

Biological Services Program

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OCTOBER 1977

COASTAL MARSH PRODUCTIVITY

A BIBLIOGRAPHY



Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.
- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.
- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

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The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staff, who provide a link to problems at the operating level; and staff at certain Fish and Wildlife Service research facilities, who conduct inhouse research studies.



COASTAL MARSH PRODUCTIVITY

A BIBLIOGRAPHY

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PREFACE

The coastal marshes of the United States are viewed herein as an ecosystem, even though many of the articles listed in this bibliography are specific to only a narrow aspect of the ecosystem. The value of the marshes is shown in many ways: habitat for wildlife species, producer of nutrients, nursery areas, and protected rearing areas for juveniles.

The report consists of an introduction prepared primarily by Dr. Armando A. de la Cruz and a bibliography compiled by Gulf South Research Institute. The bibliography consists of five major sections: Marshes and Marsh Vegetation; Primary Productivity of Marsh Plants; Detritus in the Food Chain; Marsh Estuaries as Fish Havens and; Marshes as Habitat and Feeding Grounds for Wildlife. Each of the major sections is divided into subsections that fall into a logical pattern so that a reader may work his way progressively through the materials, seeing a story unfold.

References were obtained by utilizing the abundant resources of Louisiana State University. In each case the relevant article or book was obtained and an abstract was written in terms of the specific interests of the study. As much pertinent substance as was practical was abstracted from each source with the goal that the bibliography would contain information, rather than serving merely as a reference source.

The literature survey, abstracting, and report preparation were conducted by the Resources Planning and Management Division of Gulf South Research Institute, under contract with U.S. Fish and Wildlife Service. The project leader was Jacques D. Bagur. Working under his direction were Gene A. Stephens, Harriet A. Davis, Barbara L. Woods, and Larry M. Hubbard. The initials of the person responsible for each annotation are designated in parentheses at the end of the abstract. In those cases, where the author's abstract suited the purpose of the bibliography, the reader will find the abbreviation "A.A." in parentheses.

Comments concerning the bibliography and requests for copies may be addressed to:

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COASTAL MARSH ECOSYSTEMS

PRODUCTIVITY IN COASTAL MARSHES

A marsh means many things to many people depending on the point of view of the individual. To some it is an evil smelling eyesore, a treacherous bog infested with mosquitoes. To others it represents a piece of valuable real estate with great aesthetic value. To many others, hunters and naturalists, it is a haven for a variety of wildlife. And recently, to a growing body of scientists, it represents a dynamic system of unique biological, geological and ecological interest and importance (Matthiessen 1962).

Regardless of how a marsh is described, the fact remains that it is one of the most productive types of natural ecosystems in the world. Marsh vascular vegetation, such as grasses, rushes, and sedges, produces an enormous amount of organic material that enables marshes to equal or exceed the productivity of most terrestrial communities of comparable size, even some of the most intensively managed cropland. A great quantity of literature, of both a scientific and non-scientific nature, has been published during the last decade on the subject of tidal marshes. Much of this literature extols the biological productivity of the marsh environment and emphasizes the important role this type of environment plays in the fertility of estuarine and coastal marine ecosystems.

The high fertility of tidal marshes is due basically to physical phenomena and biological processes unique to marsh estuaries (Odum 1961). Nutrient-rich estuarine waters periodically bathe these intertidal zones. Dissolved organic nutrients (e.g., phosphates and nitrates) and detrital materials enter the marsh-estuary from inflowing rivers. The saltwater wedge pushed along the estuary bottom by the incoming tide brings in other nutrients of near-shore marine origin. Currents and tides circulate and recirculate fresh and salt water, thus distributing, and to a certain extent trapping, dissolved and suspended matter. Deposition of suspended materials and flocculation of dissolved substances fertilize the marsh substrate. The plant life of the marsh, which flourishes in the nutrient-rich waters, is thus geared to year-round high production. This plant life includes vascular vegetation (grass, rush, and sedge), benthic algae (diatoms), epiphytic and mud-encrusting algae, and submerged grasses on intertidal sediments.

Vascular plants growing in marshes periodically die and enter the aquatic food chain in the form of particulate detritus, which is laden with bacteria and other microorganisms. During low tides, runoff waters and interstitial water seeping out of the mud transport high concentrations of dissolved substances such as silica, phosphate, bicarbonate, and ammonia. The estuarine waters are therefore enriched in return by the high production processes on the marshes.

The productivity of plants, referred to as primary production, is the rate at which the energy of sunlight is captured and used to build plant tissues upon which all consumer organisms are ultimately dependent. Primary productivity may be determined by measuring changes in oxygen, carbon dioxide, pH, or available raw materials; by using radioactive tracers; or by determining chlorophyll content and assimilation ratio. Primary production of vascular plants in marshes is usually measured by the harvest method, in which estimates are made of the increase in plant biomass during the growing season (Keefe 1972). The procedure involves the harvesting of plant samples periodically during the growing season. Modifications of this method take into consideration life history and phenology of the plant, as well as sampling procedures. These modifications have enabled investigators to arrive at more reliable productivity values (de la Cruz 1977).

The amount of information on the primary productivity of tidal coastal marshlands has increased steadily during the last decade. Data summarized by investigators show production values ranging from 500 to 1000 grams of dry weight per square meter for the short form of the smooth cordgrass, Spartina alterniflora; 1100 to 3000 g dry wt/m² for the tall form of S. alterniflora; 500 to 2000 g dry wt/m² for the black needlerush, Juncus roemerianus; 1000 to 2200 g dry wt/m² for the giant cordgrass, S. cynosuroides; and 993 to 1922 g dry wt/m² for the wire grass, S. patens (de la Cruz 1977). From these data, it is apparent that the primary production of marsh angiosperms varies widely from several hundred to a few thousand grams of dry organic biomass per square meter. Although this variability is believed to be due to the types of plant species involved, salinity and hydrology of the habitat, geographic latitude and temperature, and sampling methodology, a definitive study has not yet been made to demonstrate the influence of one or more of these parameters. There are indications that the marsh plants in the lower latitudes are not only bigger than their counterparts in the higher latitudes, but also more productive.

Until very recently, most of the studies concerning the primary production of coastal marshes were concerned only with plant shoots (or aerial parts), presumably because of the difficulty in sampling roots and rhizomes (or subterranean materials). The few studies available on below-ground productivity show annual production values ranging from 450 to 2500 g dry wt/m² for the short form of S. alterniflora; 500 to 3500 g dry wt/m² for the tall form of S. alterniflora; and 1360 g dry wt/m² for Juncus roemerianus (de la Cruz 1977). From these values, it is apparent that total production of marsh vascular plants is approximately double that previously reported for emergent materials.

When marsh plants die, the dead material begins at once to disintegrate under the force of wind, tides, animal trampling, and other mechanical means. As plant materials drop to the mud surface, they decompose into detritus particles largely because of microbial action (Figure 1). The rate at which detritus is formed from dead plants has been the subject of several studies. The "litter bag" method, which is the most widely used procedure to determine the rate of decomposition, measures the rate at which fragmented pieces and particles of dead plants are lost from nylon mesh bags after one year of exposure in the field. The rate is expressed as percent loss of the original material from the bags. In studies using this method, the decomposition rate was 50 to 96 percent for S. alterniflora, 35 to 47 percent for J. roemerianus, and 38 to 53 percent for Distichlis spicata. The decomposition rate of other coastal plants, including mangrove leaves, falls within these ranges (38 to 53 percent). The variation in decomposition rate is due to differences in texture and fiber strength of the marsh plant species studied, the methods used (specifically, the mesh size of the nylon bag), time intervals of measurements during the year, geographic latitude, and environmental conditions (e.g., temperature and the frequency and duration of inundation). In the studies cited, the rate is a direct function of mesh size, which varied from 1 mm to 10 mm. The environmental conditions to which the litter bags were exposed influenced the breakdown rate of plant tissues; consequently, plant materials continuously submerged decomposed faster than materials kept on the high and dry marsh. The rates also differed greatly with regard to species. In general, the tender, more succulent plants such as Salicornia and Scirpus decomposed much faster than other grasses and rushes, such as Spartina and Juncus.

Although data are not yet available on the decomposition rates of roots and rhizomes, studies on this subject are currently underway. The significance of the various components of a rhizospheric plant lies in the value of these components to the estuarine food web as an energy source, assuming that portions of the underground organic production find their way into the estuarine food web and are not totally decomposed in situ or formed into peat. Some of the below-ground material may also be lost to the system through respiration or in the production of methane by microorganisms.

Detritus is valuable as a food source because of its high source of energy and chemical constituents. There is very little energy variation in the values determined for different species of marsh plants at different phenological stages from living to dead, and through various stages of decay. The caloric content is usually slightly higher for detritus than for mature live plants. The retention of, or slight increase in, caloric content of decaying detritus is due to two factors: (1) an increase in the microflora impregnating the detritus; and (2) the retention of high organic content in the detritus, despite elemental losses. It has long been observed that the protein content of particulate detritus is

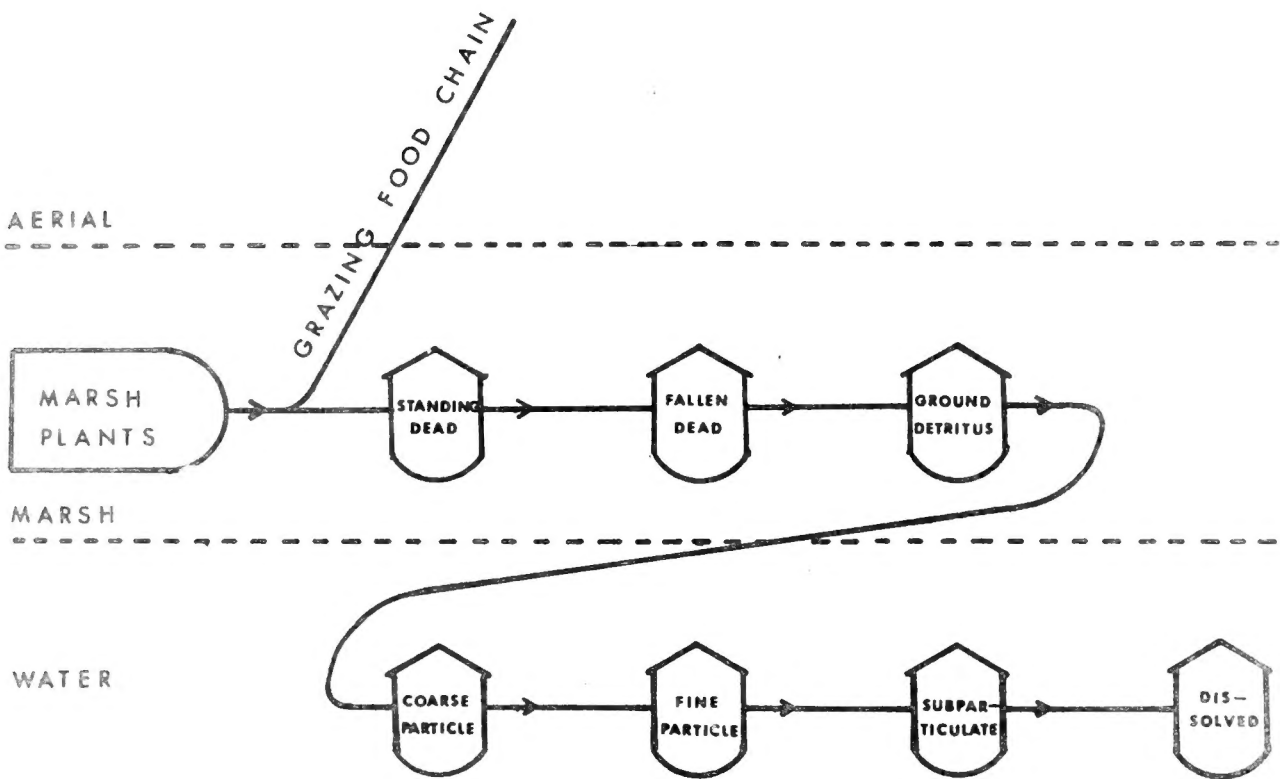


Figure 1. Schematic diagram showing potential feeding niches as provided by marsh plants at various stages of life, death, and decay.

considerably higher than that of the plant material from which it originated (Boysen-Jensen 1914). All subsequent work has shown similar results (Figure 2). The process of protein enrichment has been ascribed to the buildup in microbial population attendant to the detritus particles, such as bacteria, fungi, diatoms, and protozoa. Specific amino acids or total protein increase has been demonstrated in marsh grass, Spartina; marsh rush, Juncus; marsh sedge, Scirpus; eel and turtle grasses, Zostera and Thalassia; and mangrove leaves, Rhizophora spp. The high caloric value, high protein content, and microbial loads of the marsh plant detritus exported by tides from coastal marshes indeed represent a food source of high nutritional value to estuarine consumers.

Organic matter produced on the marsh is incorporated in estuarine waters in different forms. Dead but intact shoots of marsh plants are carried from the marsh by spring tides and by wind-driven tides, such as the seasonal storm tides. Along the south Atlantic coast, it is not uncommon to see rafts and shoals of Spartina shoots drifting out to sea with the tide. Depending on the height of the prevailing tide, 2 to 16 kilograms of floating debris can be exported during one tidal cycle from a small tidal creek draining 10 to 25 hectares (ha) of a Spartina marsh watershed. Massive accumulations of fragments from dead Juncus leaves are often seen piled along beaches and shores of the Gulf coast. Another study has shown that roughly 3 kilograms of floating debris are exported from a tidal creek draining a 6-ha marsh watershed dominated by Juncus. The back-and-forth movement of the tide breaks these materials into bits and pieces that are eventually washed out to sea.

Energy is also exported from the marsh in the form of traction materials that are rolled along the banks and bottoms of bayous and tidal creeks as the tide ebbs. It has been shown that dissolved organic substances are leached from decaying plant tissues, and that a great deal of these nutrients are leached from the marsh sediment, presumably from plant materials buried in the mud and from the massive mats of rhizomes and roots.

For the most part, however, past and current investigations have focused on the transport of energy from the marsh to estuarine waters in the form of suspended particulate detritus. The pronounced turbidity of water in bays and sounds is due primarily to the presence of detrital materials that are continuously being washed out of marshes and other wetlands by tides. The particulate detritus remains suspended in the water, and, in many instances, comprises the bulk of the particulate organic load (i.e., seston) of the water. A review of several investigations indicates that at least 90 percent of seston in marsh-estuaries is organic detritus and that the seston constituent of marine waters is generally 75 to 95 percent detritus (de la Cruz 1973).

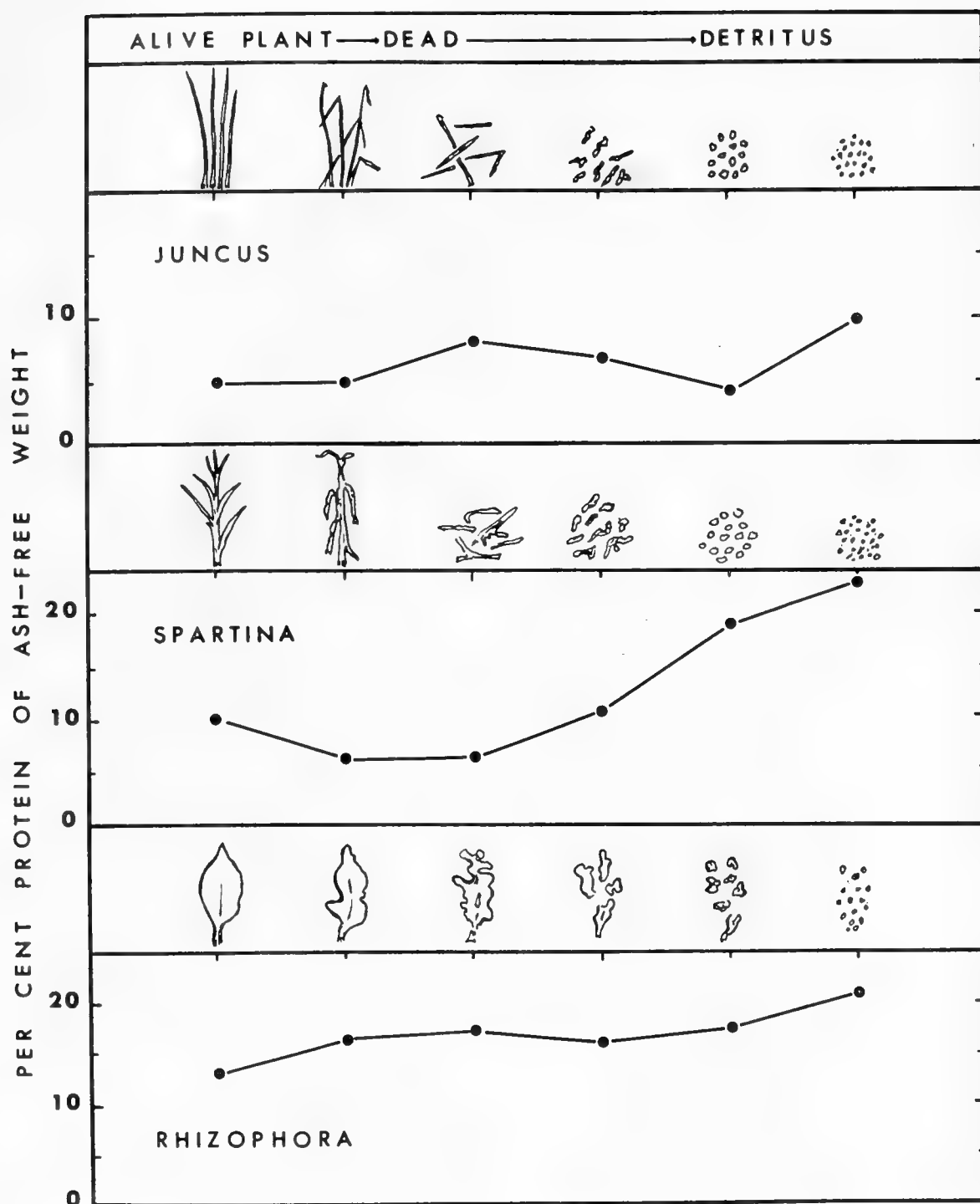


Figure 2. Increase in protein percentages in two marsh plants (*Juncus roemerianus* and *Spartina alterniflora*) and one mangrove plant (*Rhizophora mangle*) at various stages of decomposition. (From de la Cruz, 1973).

The flux of detritus to the open sea can be determined indirectly by correlating changes in concentration of sestonic detritus with changes in the standing biomass of plant materials on the marsh during the year. In a tidal system such as a marsh-estuary, the conditions in the surrounding waters are influenced by biological processes going on in the marsh. The disappearance of dead plants (source of detritus) from the marsh, beginning in winter (the period during which the dead biomass was highest because of frost-kill) and extended through fall, was inversely related to increase in detritus content of estuarine waters (de la Cruz 1973).

The transport of particulate detritus can also be estimated by measuring the net output of a tidal creek draining a known area of marsh watershed. This output has been determined to be 3.4 tons per hectare per year for a Georgia salt marsh and 3.6 tons per hectare per year for a Florida mangrove estuary. Subsequent studies have confirmed this movement of suspended detrital materials from the marsh to the aqueous system, although other investigations have indicated that the import of organic materials into tidal marshes also occur. Variations in transport direction have been attributed to hydrological characteristics such as tidal regime, to the proximity of the freshwater input, and to the geomorphic orientation of the marsh drainage system (Hackney and de la Cruz 1977). Our current investigations indicate that exports of particulate detritus are irregular in some coastal areas (e.g., Mississippi Gulf Coast) and that the marsh serves as a holding area for riverborne materials. The marshes not only export detritus to offshore waters but also regulate the overall release of organic detritus from estuaries.

The ultimate ecological value of the high primary production of a marsh occurs when suspended detritus of marsh plant origin enters the food web of the estuarine and coastal marine systems. Particulate detritus, suspended in the water and deposited on the sediment surface, is a high-quality food source for consumers because of its high energy content and nutritional value. A number of studies involving stomach analyses and experimental feeding using radioactive tracers have shown that many species of fish and invertebrates feed wholly or partially on particulate detritus.

The availability of different sizes of detritus relative to the degree of decomposition is also significant because the detritus provides energy to various feeding niches (Figure 1). Most filter feeders are presumably size-selective with regard to their food and are unable to differentiate between detritus particles and similar size plankton material. Detritus eaters, or detritivores, are important in that they form the base of the food web in the estuarine-marine environment. Detritivores are the critical link between detritus production and the production of higher consumers.

FISH AND WILDLIFE RESOURCES IN COASTAL MARSHES

Because of the high energy output and heavy standing crops of marsh-producer organisms, marshes provide food and shelter for a rich diversity of fish and wildlife resources. Otter, mink, raccoon, muskrat, and nutria are important furbearers in coastal wetlands. Game animals like the white-tailed deer and rabbit are abundant in coastal freshwater marsh areas. The habitats are also the domicile for small rodents like the hispid cotton rat and marsh rice rat which are important links in food chains of hawks, owls, foxes, and coyotes. For the rare and endangered red wolf, the marshlands of southwestern Louisiana and southeastern Texas offer a last natural refuge.

The marsh vegetation also provides construction materials for marsh-nesting passerines, rails, and gallinules. Seeds, leaves, stems, rhizomes, and tubers of marsh plants offer a varied diet for massive numbers of overwintering ducks and geese. The American woodcock, Virginia and sora rails, purple gallinule, American coot, and the common snipe are other migratory species dependent on wetland environments.

Amphibians and reptiles may reach moderate abundance in coastal habitats. Common amphibians include the lesser siren, three-toed amphiuma, and a variety of frogs and toads. Included among the common reptiles are the American alligator (which has reached commercial abundance in parts of its range), common snapping turtles, sliders and cooters, and a variety of snakes.

Tidal creeks, bays, and estuaries serve as nursery areas for early life history stages of economically important crustaceans like shrimp and blue crabs and finfishes like menhaden and croaker. In fresh to brackish marsh areas, largemouth bass, bluegill, and freshwater catfish are abundant. Oysters and clams support a thriving shellfish industry.

EPILOGUE

The alteration and destruction of marshes and other wetland habitats in favor of other land uses has encroached heavily on the sustenance of our fishery and wildlife resources. The passage of wetland protection acts in many coastal states is a major effort to protect marshlands. At the Federal level, the Coastal Zone Management Act of 1972 recognizes the vulnerability of coastal tidelands and their aqueous system to downstream influences of inland systems and the tidal influx of marine materials. The boundaries of the marsh-estuary are open to fluxes of important nutrients as well as to toxic substances; thus, the integrity of this ecosystem may be threatened by what takes place upstream in the watershed of the river mainstem and its tributaries; by the intrusion of undesirable substances from the sea as a result of offshore activity; and, more directly, by changes in the use of the water, shorelines, and wetlands of the estuarine area itself. The strategy of preservation and management, therefore, should involve a broad and comprehensive approach entailing the combined and effective implementation of local wetland acts, the Coastal Zone Management Act and its subsidiary provision on marine and estuarine sanctuaries, and legis-

lation designed to protect rivers and streams. A basic property of all natural ecosystems is that they are open-ended; that is, there is a continuous flow of energy, nutrients, and pollutants across ecosystem boundaries. To be effective, any form of environmental management must recognize this fundamental principle.

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I. THE MARSH ENVIRONMENT

A. Marshes and Related Ecosystems

I-A-1

Chapman, V.J. 1960. Salt marshes and salt deserts of the world.
Leonard Hill, London. 392 pp.

This book is a result of the author's twenty-five year study of salt marshes. Although a majority of the work centers on the salt marshes of Great Britain, the author was able to spend a year in America studying the New England marshes in some detail and to visit other American salt marshes on both the Atlantic and Pacific seaboards.

The purpose of the volume is to present a general picture of salt marshes and related tracts throughout the world. By this means, the author can depict the similarities and contrasts of salt marsh ecosystems. For example, in Chapter XI, New World Salt Marshes, the author carefully describes various salt marshes of the North American coastal periphery, showing areas of similarities and departures, yet contrasts the entire New World salt marshes with salt marshes in Great Britain and continental Europe.

The discussion on the physiology of halophytes centers on salinity and its effect on growth, transpiration, and seed germination rather than on productivity. However, the treatise serves as an excellent introduction to salt marshes and their accompanying plant species.
(L.H.)

Keywords: salt marsh ecosystems, New England, U.S. Atlantic coast,
U.S. Pacific coast

I-A-2

Odum, H.T., B.J. Copeland, and E.A. McMahan, eds. 1974. Coastal ecosystems of the United States. The Conservation Foundation, Washington, D.C. 4 vols.

This publication was originally prepared as part of the National Estuarine Pollution Survey conducted in 1968 and 1969. It is the product of a group of scientists led by staff members of the University of North Carolina Institute of Marine Sciences. The four volumes include a comprehensive survey of scientific information through 1969, as well as a new system for the classification of coastal ecosystems.

Volume I contains sections on: (1) a functional classification of the coastal ecosystems, (2) foraminifera in estuarine classification, (3) ecological systems by state, (4) general recommendations, and (5) chapters on types of ecological systems. Volume II deals with natural temperate ecosystems with seasonal programming. Volume III contains sections on: (1) natural Arctic ecosystems with ice stress, (2) emerging new systems associated with man, and (3) migrating subsystems. Volume IV is a bibliography and place index; all of the references cited in the chapters of the study are included and there are also many other references that increase its usefulness. At the end of the bibliography is a special section, Bibliography of Coastal Bibliographies, which provides special groupings as well as many titles not included in the main bibliography.

Four of the papers from this multi-volume work are abstracted elsewhere in this bibliography. (See I-A-3, I-A-4, I-A-5, I-A-6, I-A-7, I-A-8, I-A-9, IV-D-17, and I-A-10.) (B.W.)

Keywords: coastal ecosystems, foraminifera, North Carolina, U.S. general

I-A-3

Cooper, A.W. 1974. Salt marshes. Pages 55-98 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecological systems of the United States, Vol. 2. The Conservation Foundation, Washington, D.C.

This chapter presents a brief general discussion of salt marshes, vegetation, and energy flow. The two major groups of salt marshes in the United States--those characteristic of the East and Gulf coasts and those characteristic of the West coast--are discussed in detail. The author describes the various geographic regions associated with different marsh types, zonation patterns, and the marsh fauna.

Salt marsh productivity and system energy flow are described with references to important studies in the field. A third part of the chapter is a discussion of the effects of stresses on the salt marsh ecosystem. The most obvious destructive forces are those associated with improvement of navigation, land development, or refuse disposal such as dredge and fill, channelization, and spoiling.

The salt marshes at Sapelo Island, Georgia, are the most intensively studied marshes in North America and are used as a case history model for other North American salt marshes.

Information on seasonal variations in temperature, percent of incident light, salt marsh vegetation, algae productivity, annual energy flow, phosphorous flow, insect distribution, planktonic copepods, topography, sediment types, and salinity is presented in diagrams. (B.W.)

Keywords: salt marshes, marsh vegetation, energy flow, productivity, U.S. coasts, Georgia, Sapelo Island

I-A-4

Marshall, H.L. 1974. Irregularly-flooded marsh. Pages 150-170 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecosystems of the United States, Vol. 2. The Conservation Foundation, Washington, D.C.

In the southeastern United States, there is a special type of salt marsh that is only irregularly flooded with salt water and is composed mainly of a tall dark rush, Juncus roemerianus. Along the south Atlantic and Gulf coasts, irregularly flooded salt marshes are usually dominated by J. roemerianus at lower elevations and by Spartina patens and Distichlis spicata at higher elevations. These marshes are usually best developed in areas behind barrier islands and away from inlets, along the fringes of large brackish embayments, and along the lower reaches of creeks and rivers.

Good examples of this type of marsh are seen in the Pamlico Sound area of North Carolina, from Cedar Keys to Apalachee Bay in Florida, and near the mouth of the Mississippi River. Studied examples from each of three areas are discussed: Bodie Island, North Carolina; Live Oak Point, Florida; and New England.

A summary of recent research on J. roemerianus is presented, including notes on distribution, habitat factors, vertical range, morphology and growth patterns, and seasonal patterns. Marsh animals, primary productivity, the role of Juncus, and stresses imposed by man are also included. (B.W. and author's introduction)

Keywords: salt marsh, marsh grasses, marsh animals, primary productivity, U.S. South Atlantic and Gulf coasts, New England, Juncus, Spartina, Distichlis

I-A-5

Kuenzler, E.J. 1974. Mangrove swamp systems. Pages 346-371 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal Ecological Systems of the United States, Vol. 3. The Conservation Foundation, Washington, D.C.

Mangrove swamps on some coasts may be only a narrow fringe whereas elsewhere they may spread many miles inland along tidal rivers. The swamps are distinct vegetational zones dominated by a few species of moderately large evergreen trees. Mangrove trees so dominate the swamp and have such interesting properties that the autecology of the trees themselves is fairly well known, but the ecology of associated plants and animals and the energetics of the whole ecosystem are not yet thoroughly understood.

The report discusses mangrove ecological systems, including the distribution, ecology, physiology, geological role, and human use

and disturbance. The mangrove swamps of Florida and Puerto Rico are the main subject, but information from other regions is included. (B.W. and author's introduction)

Keywords: mangroves, coastal ecosystems, Florida, Puerto Rico

I-A-6

University of North Carolina Institute of Marine Sciences. 1974. Shallow salt ponds. Pages 300-314 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecological systems of the United States, Vol. 2. The Conservation Foundation, Washington, D.C.

Very shallow marine waters with good tide, wind, and wave circulation develop ecosystems in which bottom vegetation is a major photosynthetic producer such as the eelgrass, turtle grass, and algal bottoms. Many small marine estuaries of pond size not regularly flushed by the rivers belong in this category.

Examples of this type of estuary are given, and data are included for Great Pond, Falmouth, Massachusetts; Nantucket Island, Massachusetts; and Martha's Vineyard, Massachusetts. Information on refraction and transport patterns, topography, sedimentary properties, tidal currents, bottom vegetation, seasonal succession, characteristics of a low salinity salt pond, and photosynthetic production characteristics is presented graphically. (B.W.)

Keywords: tidal lakes, aquatic ecosystems, eelgrass, turtlegrass, algae, Massachusetts, U.S. coastal regions

I-A-7

Phillips, R.C. 1974. Temperate grass flats. Pages 244-299 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecological systems of the United States, Vol. 2. The Conservation Foundation, Washington, D.C.

The author presents a summary of the literature on temperate grass flats and a general analysis of the eelgrass (Zostera marina L.) system, the single most important north temperate seagrass system.

Sections are included on: geographic distribution, the ecology of eelgrass, seasonal pattern of activity, principal inputs and outputs of energy, principal food chains, characteristic mineral cycles, the economic value of the eelgrass system, disturbances and effects on the system, the interaction of the eelgrass system with developing civilization, and research needs and gaps in knowledge of the system.

Especially important is the author's recommendation that a study of the detritus contributed by eelgrass is needed, as to amount, type, chemical content, caloric value, and the effect on the physical structure of the habitat. (B.W.)

Keywords: eelgrass, food chains, detritus, nutrient cycles, energy flow, U.S. coastal regions

I-A-8

Gray, I.E. 1974. Worm and clam flats. Pages 204-243 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecological systems of the United States, Vol. 2. The Conservation Foundation, Washington, D.C.

The bottom surfaces of estuaries develop communities of invertebrate animals (annelid worms, clams, and many other organisms) that obtain foods derived from the waters above. The flat expanses of mud and sand in the inter-tidal zone and deeper in the sub-tidal bottoms, with their associated biota, are important subdivisions of the estuary. Examples of worm and clam flats and the species associated with each type are described.

Five categories of benthic feeding types are discussed: (1) deposit feeders, (2) suspension feeders, (3) scavengers, (4) carnivores, and (5) omnivores. The largest and most characteristic is the basic deposit feeding group. Deposit feeders consume not only detritus but also living diatoms and dinoflagellates. The immediate sources of organic detritus in the substrate range from dying and decaying plants and animals and solid excreta from animals inhabiting the waters, to organic debris from nearby terrestrial areas. Except in estuaries well supplied with benthic vegetation, the organic detritus is largely supplied from phytoplankton.

The author presents a picture of the normal community relations, including the relative abundance of organisms and their positions in the food web, of a typical undisturbed intertidal flat. Sources of stress which can make sudden and drastic changes in a estuary are discussed: natural phenomena, silting, heated effluents, and sewage pollution. (B.W.)

Keywords: invertebrates, estuarine organisms, detritus, community structure, U.S. coastal regions

I-A-9

Copeland, B.J., K.R. Tenore, and D.B. Horton. 1974. Oligohaline regime. Pages 315-357 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecological systems of the United States, Vol. 2. The Conservation Foundation, Washington, D.C.

The two major characteristics of oligohaline systems are low salinity and great shocks of freshwater floods. Several examples of such systems are discussed in detail: Pamlico River estuary, North Carolina; Sacramento-San Joaquin estuary, California; Baltic Sea, U.S.S.R.; and Lake Pontchartrain, Louisiana. Information is presented graphically and in narrative form.

Organisms capable of surviving the vigors of the system are few, but those that do manage to survive flourish at certain seasons of the year. Important adaptations include physical attachment to objects to avoid being swept away during high flow rates and the ability to withstand salinity variations.

Plants in the oligohaline regime include such freshwater forms as Najas and Potamogeton and the brackish water plant Ruppia maritima. Fauna include certain molluscan species that have special filtering ability to utilize the tremendous organic content of the muddy river water. Macoma balthica, Rangia cuneata, and Nereis succinea are common inhabitants of various oligohaline systems.

Migrating subsystems are important constituents of the oligohaline system and channel much of the energy harvested by man. Common among these migrating forms are the herring-like plankton feeding fishes represented by menhaden (Brevoortia patronus) on the Gulf of Mexico coast, shad (Alosa sapidissimus) and menhaden (Brevoortia tyrannus) on the Atlantic coast, shad (A. sapidissimus) and herring (Clupea pallasii) on the lower Pacific coast, and herring and cod in the Baltic Sea. Other migrating forms include carnivorous striped bass (Morone saxatilis) on the east and west coasts of the United States.

In spite of the low diversity and biomass of organisms in the oligohaline systems, the systems are relatively highly productive because of the constant influx of organic fuels via rivers from the land. (B.W.)

Keywords: aquatic ecosystems, coastal waters, salinity, filter feeders, menhaden, fishes, biomass, U.S. coastal regions

Bellis, V. 1974. Medium salinity plankton systems. Pages 358-396 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecological systems of the United States, Vol. 2. The Conservation Foundation, Washington, D.C.

This article presents a discussion of the "middle estuary." According to the author, although the precise physical limits of this part of an estuary are difficult to define, an arbitrary working definition has been accepted by many persons in the field: the characteristics of the middle estuary correspond most closely with portions of the estuary having average salinities between 5-18 ppt. The middle estuary is important because the greatest area of many North American estuaries is of this type, and it is this portion which provides primary support for certain fisheries (e.g., blue crab and oyster). In the United States all of the east coast estuaries seem to have significant middle salinity regions.

Four examples of middle estuaries are given: Chesapeake Bay; Yaquina Estuary, Oregon; San Francisco Bay system, and Galveston Bay. Middle estuaries are discussed in terms of boundaries of the system, system components, annual plankton periodicity, vertical distribution, system dynamics, and geographical variations.

One general characteristic of plankton organisms of the middle estuary is that, while they may be volumetrically abundant, they tend to be limited with respect to species variety.

Plankton organisms form the dominant biomass of the middle estuary and constitute the base of its food web. Photosynthetic production by the phytoplankton serves as a direct source of biotrophic energy inflow. A less obvious, but under some conditions equally significant, energy input derives from import into the system of dissolved and particulate organic matter.

North Carolina's sounds constitute the largest estuarine system along the Atlantic coast. Most of this vast system is of the medium salinity, plankton-based type and as such functions as a nursery or temporary home for migrating species of commercial importance. Shrimp, striped bass, and menhaden are all estuarine-dependent species. In estuarine systems such as this, efficiency of energy transfer between plant and animal is greater than in most land environments. This is because the producer components of the food web are primarily diatoms. (B.W.)

Keywords: estuaries, plankton, biomass, food web, energy flow, phytoplankton, U.S. coastal regions

I-A-11

Clark, J.R. 1974. Coastal ecosystems; ecological considerations for management of the coastal zone. The Conservation Foundation, Washington, D.C. 178 pp.

Environmental management of coastal waters and shorelands has as one of its fundamental goals the maintenance of coastal ecosystems in their best condition, or at the level of best achievable ecosystem function, which usually means as near to the natural condition as possible. This publication presents ecologic principles, management principles and rules, controls, and program elements that can be used to improve management of coastal lands and waters.

The book is intended as an overview rather than as a source of extensive background data or as a comprehensive examination of the merits of different opinions or scientific results. Sections are included on ecologic considerations relating to coastal waters and biota; ecological concepts, including productivity and the food web; environmental disturbance; resource evaluation and protection; and constraints on specific uses.

A principle that is stressed throughout the book is that no single part of an ecosystem operates independently of any other and that each coastal ecosystem must, therefore, be managed as a whole system. While attention is focused somewhat on ocean water areas, a higher degree of attention is given to estuaries because, in the opinion of the author, they tend to be more productive than either the sea or freshwater areas and they are the most sensitive and stress-vulnerable coastal ecosystems. (B.W.)

Keywords: coastal zone, ecosystems, planning and management, productivity, food web, environmental change, U.S. coastal regions

I-A-12

De la Cruz, A.A. 1976. The functions of coastal wetlands. Association of Southeastern Biologists Bulletin 23(4):179-185.

The various functions of coastal wetlands are reviewed at two levels: (1) at an ecosystem level, the use of wetlands as a whole including the intertidal zone and the immediate dryland and neighboring littoral areas for various system functions; and (2) at a component level, the use of the major biotic component, mainly the vascular plants, for various purposes.

There are many uses of coastal wetlands at an ecosystem level. These include:

1. pasture land for stock
2. habitat for birds and other wildlife
3. nursery grounds for commercial fish and shellfish
4. recreational use, which is closely related to wildlife management and fishery production in terms of sport fishing and hunting
5. component of waste treatment systems
6. transportation
7. petroleum production
8. potential use for aquaculture development

With regard to the use of coastal wetlands at a component level, the major component of coastal wetlands is the vascular plants that form the basic structure of the habitat, such as Spartina, Juncus, or Phragmites. These vascular wetlands plants and/or by-products have been harvested for a variety of uses: hut building, thatching, screens, fencing, etc. Pulp and other cellulose derivatives are produced from the common reed or roseau cane Phragmites communis. Investigations on the pharmacological potential of plants are being made. Three chemical aspects are being studied: (1) crude alkaloid content, (2) volatile oils, and (3) anti-tumor agents. Wetland plants are also potential sources of food for humans.

The author states that whether coastal wetlands are used in their natural condition or managed for other uses, the vital issue is wise use of the areas, rather than exploitation, and regulated alterations that will prevent permanent damage. (B.W.)

Keywords: coastal zone, vascular plants, coastal marshes, conservation, U.S. coastal regions

I-A-13

Teal, J., and M. Teal. 1969. Life and death of the salt marsh. Little, Brown and Company, Boston, Massachusetts. 278 pp.

This book presents an introduction to the study of marshes. It contains three parts which deal with the formation of the marshes of the East Coast; the ecology of salt marshes, including a chapter on marsh production; and marsh conservation.

Although the book is written in layman's terms, the detailed descriptions that are used to portray specific elements of a marsh are well executed. Part II, which focuses on the ecology of salt marshes, vividly describes the principal elements of this system; i.e., the dominant Spartina, marsh animals, and the various seasons associated with the marshland. Subsequent portions of Part II attempt to place these elements in proper context within the marsh ecosystem. Marsh productivity is illustrated through a comparison of the vast yields of marsh vegetation to the yields of productive acres under intense cultivation.

In summary, the book draws heavily on the scientific work from the Sapelo Island Marine Institute, yet provides interpretations of this work in an easily understood narrative format. (L.H.)

Keywords: salt marshes, ecology, productivity, Spartina

I-A-14

Hitchcock, S.W. 1972. Fragile nurseries of the sea: can we save our salt marshes? National Geographic 141:729-765.

The article elaborates on the daily phenomena of typical saltwater swamps on the Atlantic Coast. The author attempts, through descriptive passages, to isolate various segments of the swamp ecosystem and the singular role each plays in the productivity cycle: Spartina alterniflora, fiddler crab, detritus, Spartina patens, and the saltmarsh mosquito. The article is profusely illustrated with color photographs and graphics to support the narrative. (L.H.)

Keywords: productivity, Spartina, marsh ecosystems

I-A-15

Hull, R.J. 1970. A biologist's view on salt marshes. Rhode Island Resources 16(4):4-6.

This essay explains the functional roles of salt marshes and their relationship to conservation issues.

A salt marsh area has several functions: it serves as a resting and feeding site for migratory and coastal zone birds; it provides a food source for various marine animals; it is a habitat for several species of shellfish; and it serves as a breeding ground for mosquitoes. Marshes also serve as shoreline stabilizers. The thick marsh grass and underlying layers of peat withstand erosion and provide surface area for the dissipation of flood water.

An additional function of the salt marsh might be the filtering of fresh water, removing land-derived nutrients and some organic materials. Marsh grasses absorb nutrients, especially nitrates and phosphates, from water, binding them into organic structures. Marshes are also sites of primary production through the photosynthetic fixation of carbon dioxide into organic matter with the release of oxygen. The trapping of excess carbon dioxide may be another function of the salt marsh.

The author feels that commercial development of marsh areas would destroy the uniqueness and beauty of the coast, thus reducing its attraction to tourists. (H.D.)

Keywords: salt marshes, conservation, productivity, habitat

I-A-16

Odum, E.P. 1971. Fundamentals of ecology. W.B. Saunders, Philadelphia. 574 pp.

This book is a general introduction to ecology understood as the study of the totality of man and environment. It contains a chapter on principles and concepts pertaining to energy in ecological systems, which includes sections on the concept of productivity and food chains, food webs, and trophic levels. The section on productivity (20 pages) contains comparative values for the major ecosystems. The book also contains a chapter on estuarine ecology, which includes sections on food production, potential and biota and productivity. Coastal marsh plants receive particular emphasis because of their high productivity values and their contribution to the estuarine food chain. (J.B.)

Keywords: general, ecology, productivity, energy flow, food chain

B. Marsh Vegetation

I-B-1

Waisel, Y. 1972. Biology of halophytes. Academic Press, New York. 395 pp.

This book covers all of the halophytes and has a chapter on growth, including productivity. Chapter 15 provides concise discussions on many terrestrial halophytes, including Atriplex, Juncus, Spartina, and Phragmites communis, and contains partial literature citations for each species. Mangroves are discussed in Chapter 14. A 37-page bibliography, containing about 900 citations, is provided. (J.B.)

Keywords: halophytes, productivity, mangroves

I-B-2

Reimold, R.J., and W.H. Queen, eds. 1974. Ecology of halophytes. Academic Press, New York. 605 pp.

This publication arose as a result of a symposium on the ecology of halophytes sponsored by the Physiological Ecology section of the Ecological Society of America and held as a portion of the American Institute

of Biological Sciences meetings in August 1972. The interest generated in preparing and presenting this symposium pointed to the need for a review volume on the salt marsh ecosystem, the soil ecosystem, and what was known about these systems.

The publication considers the fundamentals of distribution, anatomy, and physiology of halophytes. It also provides an overview of the role of the halophyte in ecosystems in various parts of the world. A section on habitat associations of halophytes considers the relation of the plants to other fauna and flora in natural systems. A final section deals with recent applied research related to halophytes and quantification of the impact of man on the ecology of halophytes.

The publication contains 22 papers, six of which are reported on in the present bibliography. (See I-B-4, I-B-6, I-B-7, III-C-3, V-A-1, and V-A-2.) (Preface-modified)

Keywords: marsh plants, ecology, habitat, halophytes

I-B-3

Hotchkiss, N. 1972. Common marsh, underwater and floating-leaved plants of the United States and Canada. Dover Publications, New York. 124 pp.

In this unique collection, 295 illustrated marsh, underwater, and floating-leaved plants are compiled in an up-to-date guide for accurate and quick identification. Common name, scientific name, synonyms, habitat, distribution, size, identifying characteristics, and growing pattern are given for each species. (J.B.)

Keywords: marsh plants, plant guide

I-B-4

MacDonald, K.B., and M.G. Barbour. 1974. Beach and salt marsh vegetation of the North American Pacific Coast. Pages 175-234 in R.J. Reimold and W.H. Queen, eds., Ecology of halophytes. Academic Press, New York.

The objective of this paper is to survey beach and salt marsh vegetation along the Pacific Coast of North America between Point Barrow, Alaska, and Cabo San Lucas, at the southern tip of California. Although the paper does not discuss productivity, it does contain a comprehensive review of the literature on species composition and distribution. Marsh acreages are included, as well as over 100 references. (J.B.)

Keywords: marsh plants, U.S. Pacific coast, Alaska

Eleuterius, L.N. 1971. Marshes of the northern Gulf of Mexico. Page 266 in D.S. Gorsline, ed., Second national coastal and shallow water research conference; abstract vol. University of Southern California, Los Angeles. (Abstr.)

Although there is increasing evidence to indicate that the coastal marshes are indispensable areas of primary productivity and habitats for myriads of animals, destruction of these marshes continues. Recent legislation has retarded large-scale destruction somewhat, but small increments are slowly being lost. This piecemeal destruction appears to be the most common form in the north Gulf of Mexico marshes at present where little or no work has been done on the re-establishment of plant habitats destroyed in engineering operations. Marshes have become the catch basins for upland pollutants and the effect on the vegetation has been largely ignored by researchers. The most obvious effects are the reduction in number of vascular species and the drastic change in the algal species.

Most of the tidal marsh in North America occurs in the northern Gulf of Mexico. However, more studies on marsh vegetation have been conducted on the Atlantic Coast. Very little is known about the plant ecology of the marshes found in the northern Gulf, and care should be taken in extrapolation of Atlantic Coast data.

A thorough knowledge of the ecology of the major marsh species is essential before any successful attempt can be made to manage undisturbed marshes and rehabilitate areas adversely affected by man.

Some important marsh plants that are being studied are Juncus roemerianus, Spartina alterniflora, Scirpus olneyi, Spartina patens, Spartina cynosuroides, Scirpus validus, Cladium jamaicense, Phragmites communis, and Distichlis spicata. Detailed studies on the growth patterns and productivity for each species are being conducted and correlated to ecological data collected throughout the year. Successional variation in the marsh composition is being obtained throughout the growing season, and seasonal changes are being recorded. The leaves, rhizomes, and roots of plants from various habitats are being measured to obtain meristic data for comparison. Studies on seed germination, seedling development as well as some genetic, physiological and anatomical work are in progress. All of these studies will lead to a better understanding of the vegetation of the undisturbed marsh and assist in the rehabilitation of disturbed areas. (A.A.)

Keywords: coastal marshes, environmental change, vascular plants, algae, tidal marsh, U.S. Gulf coast

I-B-6

Duncan, W.H. 1974. Vascular halophytes of the Atlantic and Gulf coasts of North America north of Mexico. Pages 23-50 in R.J. Reimold and W.H. Queen, eds., Ecology of halophytes. Academic Press, New York.

Difficulties in delimiting halophytes and halophytic habitats are discussed and an annotated list of halophytes is presented. Data included for each species are: the halophytic habitats in which they are reported to occur, the authors reporting the habitats, page citations for these reports, and composites of the coastal geographic distributions compiled from numerous authors. The list of halophytes includes 347 species in 177 genera and 75 families. The possibilities that some species may be erroneously listed and others omitted are discussed. Geographic distributions are analyzed by areas and summarized. Although the article does not report on productivity, it forms a good base for the study of the Atlantic and Gulf Coast marsh plants. Some indication of the relative richness of the halophytic vegetation in different regions of the coast is given by the total numbers of species reported for the regions; namely, 133 species along the Gulf Coast from Texas into Alabama, 197 species from Georgia into Delaware, 161 species from New Jersey into Maine, and 125 species in Canada. (A.A. and excerpt)

Keywords: halophytes, marsh plants, U.S. Atlantic and Gulf coasts

I-B-7

Walsh, G.E. 1974. Mangroves: a review. Pages 51-174 in R.J. Reimold and W.H. Queen., eds., Ecology of halophytes. Academic Press, New York.

The references at the end of this review include over 1,200 published accounts of mangroves. The author has attempted to review the major conclusions of these published accounts and to give a picture of the contemporary state of knowledge with respect to geographical distribution, ecology, adaptations, silviculture, and herbicides. A subsection on energy relationships discusses all of the mangrove productivity studies completed as of 1972. (J.B.)

Keywords: mangrove, productivity, ecology

I-B-8

Chapman, V.J. 1969. Lagoons and mangrove vegetation. Pages 505-513 in A.A. Castanares, ed., Coastal lagoons, a symposium. Universidad Nacional Autonoma de Mexico, Ciudad Universidad.

There are two classes of saltwater lagoons: bodies of water separated from the sea by a sandbar and the shallow water area in the center of a coral atoll or cay. If the term is extended to include sounds and calderas,

at least three types of angiosperm vegetation can be associated with lagoons. In temperate regions, there can be salt marsh and eel-grass meadows while in the tropics there will be marine grass meadows and mangrove vegetations. In addition, marine algae will be associated with all three types. There are three major types of substrate upon which the angiosperms can grow: mud, sand, and coral. The latter is occupied only by mangrove trees. The environmental factors vary depending upon the kind of lagoon. Tidal movement may be pronounced or greatly dampened if the lagoon is wholly cut off from the sea. Salinity may be that of ocean water; it may be much less if a major river enters the lagoon, or in the tropics the water may become hypersaline through evaporation. Atoll lagoons will tend to have clear water except during storm periods, whereas in sounds and calderas the water is turbid from suspended silt, and the geological work of salt marsh and mangrove plants can be very significant. Currents, especially in sounds, must affect mangrove distribution, while wave action will have an effect upon the aquatic phanerogams. Accretion of sand and mud brings about slow elevation of the land and the gradual narrowing of the lagoon through the slow and steady invasion of mangrove and salt marsh plants. In enclosed lagoons water temperature may rise considerably above that of the external seawater, but this does not materially affect mangroves. A few measurements have been made of the biomass of mangrove, sea-grass meadows, and salt marsh. In view of the proximity of many lagoons to human settlement, there is a tendency for many lagoons to be polluted to a lesser or greater degree. Man is increasingly being faced with the problem of how far he is prepared to let pollution affect his waterways and other natural water areas. The preservation of some typical lagoons and their vegetation is also a matter of urgency. This applies particularly to coastal lagoons, but cannot be ignored even in the case of atoll lagoons (A.A.--modified)

Keywords: mangroves, estuaries, salt marshes, eelgrass, coastal lagoons

C. Marsh and Estuarine Conferences

I-C-1

Marine Institute of the University of Georgia. 1959. Proceedings of the salt marsh conference, Sapelo Island, Georgia. University of Georgia, Athens. 133 pp.

The idea for the conference was conceived when it was learned that the National Science Foundation was interested in encouraging meetings of limited numbers of people to discuss specialized subjects, especially those topics that cut across the boundaries that traditionally separate scientific disciplines. The study of salt marshes is clearly an interdisciplinary

effort, drawing the attention of geologists, hydrographers, botanists, zoologists, and others. One of the main purposes of the meeting was to advance the recognition of salt marshes as a coherent subject for general scientific study.

Some fifty-five participants from university and government agencies throughout the U.S. and the world gathered at the Marine Institute of the University of Georgia at Sapelo Island to discuss four principal topics: salt marshes as land forms, salt marshes as vegetation, the salt marsh as an ecosystem, and salt marshes as historical records. Of the 22 papers presented, four have been selected for individual consideration in this bibliography. (See II-B-13, II-C-1, III-C-4, and III-E-6.) (G.S.)

Keywords: general, salt marshes, productivity, Spartina, energy flow

I-C-2

Newsom, J.D., ed. 1968. Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge. 250 pp.

Marshes and estuaries, which are fertile and valuable land and water areas, serve as production areas and nursery grounds for many marine organisms. They are also valuable in the production of fur animals and many species of game and nongame birds. Productivity of these areas is being threatened by such forces as industrial and domestic pollution, dredging, channelization, and urbanization. This symposium was held in an attempt to focus national attention on the value of these areas, as well as on some of the complexities of marsh and estuarine management. Articles discussing the values of South Atlantic and Gulf coast marshes and estuaries to fish and wildlife are abstracted elsewhere in this publication. (See IV-A-4, IV-C-2, IV-C-4, IV-C-6, IV-E-2, V-B-9, V-B-10, and V-C-2.) (B.W.)

Keywords: salt marshes, estuaries, productivity

I-C-3

Chabreck, R.H., ed. 1973. Proceedings of the coastal marsh and estuary management symposium. Louisiana State University, Baton Rouge. 316 pp.

The Second Symposium on Coastal Marsh and Estuary Management was organized because of the growing concern for problems within the coastal zone. A major purpose of the symposium was to assemble experts in the field of coastal marsh and estuary management and to exchange ideas on events that had transpired since the first symposium. Introductory presentations highlighted recent developments in coastal zone planning and administration. Productivity was the major theme of the symposium, and attention was paid to primary as well as secondary productivity.

Discussion on factors affecting productivity centered on current use of the coastal zone and probable future demands. Of the nineteen papers presented during the symposium, six have been abstracted in this bibliography. (See II-E-7, III-A-9, IV-A-5, IV-D-5, IV-E-1, and V-A-4.) (J.B.)

Keywords: estuarine management, coastal zones, productivity

I-C-4

Cronin, L.E., ed. 1975. Estuarine research, Vol. 1. Academic Press, New York. 738 pp.

This book is one of the first of a biennial series planned by the Estuarine Research Federation to present new information and concepts relating to the estuaries of the world. Volumes 1 and 2 contain papers presented in the Second International Estuarine Research Conference held by the Federation at Myrtle Beach, South Carolina in October of 1973. The Conference was cosponsored by the American Society of Limnology and Oceanography and by the Estuarine and Brackish Water Sciences Association.

Volume 1 is divided into three major sections: Chemistry (Cycling of Elements in Estuaries), Biology (Dynamics of Food Webs in Estuaries), and the Estuarine System (Estuarine Modeling). A number of the biology articles are concerned with various aspects of estuarine productivity. These are abstracted elsewhere in this bibliography (see II-D-6, III-B-1, III-D-4, III-D-9, III-E-4, III-E-19, III-F-25, III-F-26, and IV-F-5). (G.S.)

Keywords: estuaries, productivity, U.S. general

I-C-5

Lauff, G.H., ed. 1967. Estuaries. American Association for the Advancement of Science, Washington, D.C. 757 pp.

This book is a product of the Conference on Estuaries, held at Jekyll Island, Georgia, from March 31 to April 3, 1964. The objectives of the conference were to provide an opportunity for the exchange of ideas between the various disciplines and individuals interested in estuarine research, to summarize the present knowledge of the natural characteristics of estuaries, and to identify the directions of current research efforts.

The subject is broad and includes aspects of biology, chemistry, geography, geology, and physics. The book is divided into eleven major sections: basic considerations; physical factors; geomorphology; sediments and sedimentation; microbiota; nutrients and biological production; ecology and populations; physiology and evolution; fisheries;

human influences; and summary. A number of the articles are concerned with various aspects of estuarine productivity. These are abstracted elsewhere in this bibliography. (See III-A-6, III-A-10, III-B-3, III-E-21, III-D-10, III-D-11, III-E-24, IV-B-6, IV-C-3, and IV-D-1.) (H.D.)

Keywords: general, estuaries, productivity

I-C-6

Castanares, A.A., ed. 1969. Coastal lagoons, a symposium. Universidad Nacional Autonoma de Mexico, Ciudad Universidad. 686 pp.

This book contains fifty papers presented at the Symposium on Coastal Lagoons, which was held in Mexico City in November 1967. The symposium was an international conference, and the papers are a fair representation of the state of knowledge of coastal lagoons at the time, including their origin, dynamics, and productivity. Faunal and floral productivity and interrelationships are covered. Four papers relevant to this bibliography, including two on mangroves, are abstracted elsewhere. (See I-B-8, IV-D-19, IV-F-1, and V-A-9.) (J.B.)

Keywords: general, coastal lagoons, productivity, mangroves

D. Comprehensive Area and Site Studies

I-D-1

U.S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife. 1970. Estuarine Landscape Survey and Analysis. Vol. 4 in National Estuary Study. Washington, D.C. 128 pp.

The entire study, consisting of a main report and eleven appendixes, was completed in response to a directive from Congress authorizing the Secretary of the Interior to carry out a study of the nation's estuaries in accordance with the Estuary Protection Act (P.L. 90-454).

Narrative portions of the main report are general in scope and content. Appendix D, on the other hand, represents the results of survey and analysis of present landscape values associated with coastal estuaries within the United States. The report is divided into two parts. Part I introduces a classification system for coastal landscapes and presents a survey and analysis of U.S. coasts. The analysis includes an ecological and landscape assessment of each of the ten U.S. coastal regions identified and delineates these findings onto a series of maps, by region and by resources within that region. The maps, entitled Biotic Resources, carefully define a region according to (1) wetland areas, (2) waterfowl zones, (3) prime shellfish areas, etc.

Part II describes the classification system used in Part I and details general principles for guiding development and land use in response to landscape characteristics. (L.H.)

Keywords: estuaries, general, U.S. coastal regions

I-D-2

Hay, J., and P. Farb. 1966. The Atlantic shore. Harper & Row, New York. 246 pp.

Although written for a general audience, this book contains technical information on the various aspects of the Atlantic shore. Chapters on shore patterns, zonations, beaches and dunes, tidal flats, salt marshes, animals and birds, and man's influence on the shore are included. Habitat, feeding habits, adaptability to change, and migration patterns of animals and birds are discussed. Vegetation is described in general terms. (B.W.)

Keywords: zonation, tidal flats, salt marshes, habitat, birds, U.S. Atlantic coast

I-D-3

McNulty, J.K., W.N. Lindall, Jr., and J.E. Sykes. 1972. Cooperative Gulf of Mexico estuarine inventory and study, Florida: phase 1, area description. U.S. Department of Commerce, NOAA Technical Report NMFS CIRC. 368. 126 pp.

This study represents a portion of the larger Cooperative Gulf of Mexico Estuarine Inventory, which was conducted in the Gulf Coast states--Alabama, Florida, Louisiana, Mississippi, and Texas.

Newly developed tables and maps depict the dimensions, submerged vegetation, tidal marshes, mangrove swamps, commercial oyster beds, leased oyster-rearing areas, sources of pollution, drained tidal marshes, and filled areas of Florida's west coast estuaries. Published and unpublished information on temperature, salinity, geology, artificial fishing reefs, stream discharge, human population, commercial fishing, and economic development is presented in new form.

If the total area of estuaries (3,003,312 acres) is considered to be the area of open water (2,081,525 acres) plus the area of mangrove swamps (393,160 acres) and tidal marshes (528,528 acres), then roughly one-half of the total area of estuaries is unvegetated; the remaining half is about equally divided among mangroves, tidal marshes, and submerged vegetation.

Human population in coastal counties increased from 614,616 in 1930 to 3,320,226 in 1970, resulting in adverse effects

from pollution to 43 percent of estuarine areas, filling of 23,521 acres mainly for residential and industrial development, and draining of 26,676 acres of tidal marshes for mosquito control. Increasing population correlates directly with the number of sources of pollution, filled area, and the area closed to shellfishing by public health authorities; thus, failure to control the adverse effects of population growth will clearly result in continued rapid degradation of estuarine habitat on Florida's west coast. (A.A.)

Keywords: coastal marshes, mangroves, oyster beds, estuarine vegetation, Florida Gulf coast

I-D-4

Christmas, J.Y., ed. 1973. Cooperative Gulf of Mexico estuarine inventory and study, Mississippi. Gulf Coast Research Laboratory, Ocean Springs, Mississippi. 434 pp.

This study represents a portion of the larger Cooperative Gulf of Mexico Estuarine Inventory and Study, which was done in cooperation with the National Marine Fisheries Service and was conducted in the Gulf Coast states--Alabama, Florida, Louisiana, Mississippi, and Texas. The publication consists of four phases of study: area description, hydrology, sedimentology, and biology. Lists of references follow each section.

Phase I, area description, contains a discussion of the estuarine basin, principal environmental factors, special benthic features, and pollution. This section is general and provides an overview of the study area.

Phase IV, biology, contains more detailed information on the marshes, distribution of flora, seasonal and areal distribution of invertebrate and vertebrate species, and plankton distribution.

Juncus roemerianus dominates the marshes of Mississippi. Freshwater marshes exhibited a great diversity of plant species, whereas saline marshes were more homogeneous with few species. Marsh regions, based on species composition, were established and zonation of each region was recorded. Total standing crop and annual production was estimated at 3 million tons.

Approximately 20,000 acres or 31.2 sq. mi. of submerged vegetation were located in the Mississippi Sound study area. The species of greatest abundance was Diplanthera wrightii, followed by Cymodocea manatorum, Thalassia testudinum and Ruppia maritima, in that order. Halophila engelmanni was found in only one locality and was considered to be of rare occurrence. Red algae dominated certain areas and was found in association with all the other plant species except Ruppia maritima, which is located near the mainland shore

in low-salinity waters and in ponds on Horn and Cat Islands. Red algae made up a large part of the marine flora of Mississippi Sound, based on abundance and species diversity. Brown algae were found along with red algae. Green algae occur in abundance along the mainland shore in Spartina alterniflora marshes and on oyster shells in the brackish bays. The approximate acreage of Mississippi Sound covered by submerged marine spermatophytes and algae is presented.

Copepods were the dominant zooplankton group. Acartia tonsa was the most abundant plankton species.

The influence of the ctenophore Mnemiopsis mccradyi on plankton volume is discussed. These predators probably play a large role in regulating the distribution and abundance of local plankton populations.

The occurrence, relative abundance, seasonal and areal distribution, and distribution of invertebrates within the salinity-temperature matrix collected in trawl, seine and sediment samples in the Mississippi Estuarine Study Area were reported. White shrimp and brown shrimp were the two most abundant species. Shrimp, crabs and oysters provided all of the reported commercial landings of invertebrate species. Squid (Lolliguncula brevis) was the fourth most abundant species.

The occurrence, relative abundance, seasonal and areal distribution, distribution in the salinity-temperature matrix, spawning and growth rate of fishes collected with trawls and seines in the Mississippi estuarine study area were reported. A list of 294 fish species from Mississippi estuaries and continental shelf waters off Mississippi included 251 species observed in the estuarine study area. The bay anchovy (Anchoa mitchilli), largescale menhaden (Brevoortia patronus), Atlantic croaker (Micropogon undulatus), spot (Leiostomus xanthurus), butterfish (Perilus burti) and sand seatrout (Cynoscion arenarius) comprised 93 percent of the total number of fishes collected. Over 93 percent of the number of fishes caught were in the families Engraulidae, Clupeidae and Sciaenidae. The role of other vertebrates in the study area is discussed.

The bay anchovy was not sought by commercial fishermen. The other five species most abundant in the study area contributed about 93 percent of the total commercial finfish landings in Mississippi. (A.A. and B.W.)

Keywords: estuarine areas, coastal marshes, plankton, aquatic fauna, marsh grasses, Mississippi

I-D-5

Louisiana Wild Life and Fisheries Commission. 1971. Cooperative Gulf of Mexico estuarine inventory and study, Louisiana. 2 vols.

The study represents a portion of the larger Cooperative Gulf of Mexico Estuarine Inventory and Study, which was done in cooperation with National Marine Fisheries Service and was conducted in the Gulf Coast states--Alabama, Florida, Louisiana, Mississippi, and Texas.

The first volume contains the sections devoted to area description and biology, phase 1 and phase 4, respectively. The second volume contains phase 2 and phase 3 of the study and deals with hydrology and sedimentology.

The basic data of the area description phase involved the following: (1) vegetation type mapping; (2) calculations of surface water acreage and water volume of the coastal zone; (3) fresh water discharged into the estuarine zone; (4) public, private, and artificial shell reefs, which would indicate the distribution and abundance of the oyster resources; (5) population statistics of the estuarine zone; (6) sources of pollution; and (7) an economic appraisal of the importance of the commercial fishery.

The biology phase is composed of two sections: (1) fishes and invertebrates collected in trawls and seines, and (2) zooplankton. A total of 100 species of fishes and 19 species of invertebrates were collected. Areal and seasonal distribution of these species is discussed. Data on historical commercial fisheries are presented. Zooplankton results indicated a spring and fall maximum in the study area. Total counts ranged from a minimum of 116 per 100/m³ to a maximum of 377,393 per 100/m³. (A.A. and B.W.)

Keywords: coastal marshes, estuarine areas, fisheries, zooplankton, Louisiana

I-D-6

Crance, J.H. 1971. Description of Alabama estuarine areas--cooperative Gulf of Mexico estuarine inventory. Alabama Marine Resources Bulletin No. 6. 85 pp.

This study represents a portion of the larger Cooperative Gulf of Mexico Estuarine Inventory and Study, which was done in cooperation with the National Marine Fisheries Service and was conducted in the Gulf Coast states--Alabama, Florida, Louisiana, Mississippi, and Texas.

The physical characteristics of Alabama estuarine areas are presented. The importance of estuaries as nursery areas for marine species and for

other uses is discussed, and the early history of the exploration and development of the Gulf of Mexico and the coastal area of Alabama is reviewed.

Maps are presented to show the Alabama estuarine study area and the surface sediment types, pollution sources, oyster beds, isotherms, isohalines and certain economic characteristics of the area. Data on climate, tides, open water surface area and average depth, tidal marsh, stream discharge, domestic and industrial wastes, navigation channels, commercial fisheries, and other characteristics of the study area are presented in tables.

Alabama estuaries are located in Mobile and Baldwin counties, which are underlain by the Citronelle Formation, which contains estuarine deposits of Miocene Age. The climate is strongly influenced by the Gulf of Mexico. Rainfall at Mobile averages about 62 inches a year, and the average annual temperature is about 68°F. The mean diurnal tide range in the study area is about 0.5 to 1.8 feet. Mobile Bay, the predominant estuarine system, has a surface area of 264,470 acres and a drainage basin of over 44,000 square miles.

The Alabama estuarine study area has 397,353 acres of open water (a volume of 3,833,489 acre-feet at mean high water), 34,614 acres of tidal marsh, 433 miles of bay and open water shoreline, 306.8 miles of streams, 3,064 acres of natural oyster reefs, approximately 924 acres of leased oyster bottoms and 1,050 acres of riparian bottoms used to grow oysters. In July 1970, there were 23 sources of municipal wastes and 31 sources of industrial waste that discharged a minimum of 827.3 million gallons of effluents daily into the estuaries and nearby contributory streams. The effluents were equivalent to untreated sewage of 634,190 persons. There were 73,594 acres of estuarine water permanently closed to the harvest of shellfish, 143 miles of navigation channels, and 2,152 acres of emergent spoil banks and other filled areas in the estuaries in 1970. Total human population of Mobile and Baldwin counties in 1960 was 366,400. It is expected to increase to 629,000 by the year 1995.

A second section of the study appears in the Alabama Marine Resources Bulletin No. 7 and deals with the hydrology of the estuarine areas. (A.A. and B.W.)

Keywords: estuarine areas, nursery areas, fishery resources, Alabama

I-D-7

Woodwell, G.M., and E.V. Pecan. 1973. Flax Pond: an estuarine marsh. Brookhaven National Laboratory, Upton, New York, Report No. BNL-50397. 7 pp.

Research has been developed around an estuarine, marsh, Flax Pond, in the Village of Old Field on Long Island's north shore. The marsh

is connected to Long Island Sound through a single channel and is flushed twice daily by the tide. Amount of freshwater entering the marsh is small. The topography is simple enough that there is a possibility of making detailed budgets of inputs and outputs of carbon and other nutrients essential for life. This report describes the marsh--its history, topography, vegetation, hydrology, and physical dimensions--and outlines current research. At high tide, the area of water is about 574,000 sq m; volume is about 880,000 cu m; salinity averages 26 percent; mean tidal range is about 1.8 m. The tidal pattern varies little over the year; the duration of ebb tide is usually two hours longer than that of the flood due to a sill in the entrance of the channel. Principal vegetation is Spartina alterniflora. Details of the pond's structure and function are being accumulated to the point where this estuarine marsh is one of the most thoroughly known such sites in the world. Chemistry, sediments, vegetation, and fish are described. (A.A.)

Keywords: salt marshes, nutrients, Spartina alterniflora, Long Island

I-D-8

Emery, K.O. 1969. A coastal pond. American Elsevier Publishing Company, New York. 80 pp.

Oyster Pond is a freshwater pond on the southern coast of Cape Cod. This study investigates all aspects of the pond and its plant and animal life. Beginning in April and continuing until November, areas shallower than about one meter are partly covered by Ceratophyllum demersum (coontail), Potamogeton crispus (pondweed), and P. foliosus (leafy pondweed). Also present are Zannichellia palustris (?) and Xyris congdoni (?). These sessile plants probably comprise a large part of the food supply that makes the pond attractive to birds. During the summer period of greatest growth, masses of the plants break away from the bottom and drift about the pond. Their remains are found on the bottom, to which they contribute organic matter, although probably less than is provided by phytoplankton.

Little benthic animal life is present except along the pond shores. In contrast, so many fishes live in the pond that their requirements exceed their food supply at least seasonally, so that they have become somewhat dwarfed. The base of the food pyramid for all animals is the very abundant planktonic algae that impart a light green color to the water and that have an annual primary productivity of about 400 gm of carbon per square meter per year. Most of this organic carbon is oxidized to carbon dioxide through respiration by the plants and animals that live in the pond. Somewhat less than 10 percent of it is carried to the ocean within the overflowing water from the pond, and a bit more than 10 percent of it is buried in the bottom sediment each year. Because of the high productivity and the

incomplete oxidation of the organic debris, the bottom sediments contain a rich assemblage of amino acids, sugars, and many other organic compounds whose future study may provide much biochemical interest. (J.B.)

Keywords: freshwater ponds, biology, plankton, productivity, Cape Cod

I-D-9

Barbour, M.G., R.B. Craig, F.R. Drysdale, and M.T. Ghiselin. 1973. Coastal ecology: Bodega Head. University of California Press, Berkeley. 338 pp.

Bodega Head is a small coastal peninsula about 65 miles north of San Francisco. It consists of six major habitat units: grassland and ocean-facing cliffs; rocky intertidal zone; beach and dunes; saltwater marsh and mudflat; freshwater marsh and seasonally wet areas; and areas transformed by human activities. The vegetation and wildlife of each habitat are discussed in detail, as well as man's impact.

The major plant species in the saltwater marsh and mudflat are saltgrass (Distichlis spicata), pickleweed (Salicornia virginica), bulrush (Scirpus americanus), arrow grass (Triglochin maritima), jaumea (Jaumea carnosa), annual bulrush (Scirpus koilolepis), bird's beak (Cordylanthus maritimus), and plantain (Plantago lanceolata). The freshwater marsh is dominated by sow thistle (Sonchus asper), velvet grass (Holcus lanatus), rushes (Juncus leseurii and Juncus bolanderi), cinquefoil (Potentilla egedei), willow herb (Epilobium adenocaulon), clover (Trifolium worskioldii), hairy cat's ear (Hypochoeris radicata), curly dock (Rumex crispus), horsetail (Equisetum arvense), bull thistle (Cirsium vulgare), fireweed (Erechtites prenanthoides), monkey flower (Mimulus guttatus), oenanthe (Oenanthe sarmentosa), and bur reed (Sparganium eurycarpum). The grasslands are dominated by sea pink (Armeria maritima), golden yarrow (Eriophyllum staechadifolium), poppy (Eschscholzia californica), ryegrass (Lolium multiflorum), lichens, lupine (Lupinus arboreus), sheep sorrel (Rumex acetosella), and ripgut (Bromus diandrus). Productivity values are given for the grassland, but not for the marshlands.

The strand and dunes and, in particular, the mudflat community and its suburbs are of interest as habitat. The former is in context of a low foredune, built up by constant deposits of sand and the congealing power of plant roots, which separates the strand from the central dunes of Bodega Head. Gradients in the microenvironment are discussed in terms of soil texture and terrain, temperature and wind, and salinity and wind. There is also a discussion of zonation of organisms.

Plant cover was measured along the entire dune transect. The importance of each species to the community was estimated, and plant cover in each area is summarized in tabular form, according to three segments:

strand and foredune, central dunes, and hinddune. Included are beachgrass, lupine, evening primrose, thistle, and rush. A number of animal species were found to build up large populations, although species diversity was low in the area. Sand crabs, arthropods, insects, and some species of birds are discussed.

The mudflat (and sandflat) community is described as habitat in chapter 5. Mudflats are considered to be extremely productive. The surface and subsurface mud contains an abundant population of small plants (mainly diatoms). At lower levels, extensive beds of eelgrass occur. The marsh is found to contribute much food. It is therefore concluded that the mudflat gives more energy to the rest of the world ecosystem than it receives. When the tide comes in, it brings food to the mudflat animals, and also brings in animals that feed on both animals and plants. When the tide goes out, the inhabitants are exposed to another group of predators and herbivores and to the drying action of air. Burrowing is found to ameliorate these conditions somewhat.

Plant and animal zonation of organisms and communities are discussed in terms of four zones. Plants tabulated include salt grass, pickleweed, bulrush, arrow grass, and jaumia. Animals are less conspicuous, but include burrowing shorecrabs and other small crustaceans, gastropods, etc. Nonresident vertebrates (birds and fishes) and insects are also discussed, along with community structure in the mudflat ecosystem. (G.S.)

Keywords: salt marshes, halophytes, freshwater marsh, freshwater plants, wildlife, habitat, mudflat communities, California

II. PRIMARY PRODUCTIVITY OF COASTAL MARSH PLANTS

A. Productivity of Coastal Environments

II-A-1

Westlake, D.F. 1963. Comparisons of plant productivity. *Biological Reviews of the Cambridge Philosophical Society* 38:385-425.

This article discusses the principles of comparative productivity and the net primary productivity of different types of plant communities. The author defines primary production as weight of new organic matter created by photosynthesis over a period of time. This is expressed as a rate. Several other pertinent definitions are also provided.

Ways of adjusting source data to a common form are examined at length, for meaningful comparisons are impossible if this is not done. Source data are published according to a great variety of criteria such as fresh weight, dry weight, oxygen production, and carbon fixation. Standing crop or yield data need correction for omitted parts of the plant. The determination of productivity from changes in biomass may involve corrections for material accumulated from earlier periods and for losses due to death or grazing. Conversions from gross production to net production are usually required when photosynthetic determinations are made.

Problems raised by the use of different units are discussed, and selected factors are listed for conversions to the recommended units. The basis adopted for comparisons is the maximum average annual net productivity of organic (ash-free) matter that can be attained over a large area. This facilitates the comparison of the productivity of different types of communities by minimizing differences due to local site conditions and weather, and is the most useful measure for general ecological purposes. For some selected examples, the productivity and biomass are expressed in a variety of other ways to facilitate direct comparisons with source data.

Methods for determining productivity are only discussed insofar as the details affect the comparability of the results. The most productive temperate communities appear to be fertile reed-swamps, which may produce 30 to 45 metric tons per hectare (m.t./ha.) in a year. Coniferous forests and perennial plants under intensive cultivation may produce 25 to 40 m.t./ha. Deciduous forests, uncultivated herbs and cultivated annual plants are less productive (10 to 25 m.t./ha).

The phytoplankton of lakes and oceans is relatively poor in terms of productivity, even on fertile sites, with an annual production of only 1 to 9 m.t./ha. Values greater than 3 m.t./ha. are achieved only in waters enriched by man's activities or in the tropics. Submerged freshwater macrophytes are no more productive in the temperate region, but may attain 13 to 21 m.t./ha. in warmer climates. Benthic marine plants in shallow waters may produce more; from 25 to 33 m.t./ha. in

the temperate zone, rising to nearly 40 m.t./ha. by tropical coral reefs. Algae cultivated in sewage can produce up to 45 m.t./ha., and algae cultivated in mineral media, with carbon dioxide supplied artificially, may produce even more. Comparative data on productivity and biomass are provided for phytoplankton, seaweed, algae, and grasses. (Author's summary)

Keywords: productivity, biomass, phytoplankton, algae, marine plants

II-A-2

Cooper, J.P., ed. 1975. Photosynthesis and productivity in different environments. Cambridge University Press, London. 715 pp.

This book is the latest and most comprehensive work on productivity in different environments, including the aquatic environment. It was published under the auspices of the International Biological Programme, which was established by the International Council of Scientific Unions in 1964 as a counterpart of the International Geophysical Year. The subject of the International Biological Programme, which ended in June 1974, was "The Biological Basis of Productivity and Human Welfare." The programme brought together scholars from all over the world to promote basic knowledge relevant to the needs of man and produced a series of volumes. Photosynthesis and Productivity in Different Environments is the third volume in the series. It contains sections on primary production in terrestrial ecosystems, primary production in aquatic ecosystems, distribution of radiant energy, photosynthetic activity of individual plants, use of assimilates, influence of stress factors, actual and potential production, and conclusions. The section on primary production in aquatic ecosystems contains five chapters. Two of these are abstracted elsewhere in this bibliography. (See II-A-3 and II-A-4.) (J.B.)

Keywords: general, productivity, aquatic ecosystems

II-A-3

Mann, K.H., and A.R.O. Chapman. 1975. Primary production of marine macrophytes. Pages 207-225 in J.P. Cooper, ed., Photosynthesis and productivity in different environments. Cambridge University Press, London.

Areas of extremely high primary productivity are found within a comparatively narrow zone at the edge of the sea. In some instances, the rate of production is comparable with that of tropical rain forests. The plant forms of the littoral zone are varied, including seaweeds, sea grasses, marsh grasses, and mangroves. The highest rates of productivity are found in the brown algae, Laminaria and Macrocystis, which live subtidally on temperate and subarctic rocky shores, and achieve annual net production in the range 1000-2000 gCm⁻². Marsh grasses

such as Spartina may produce 200-1000 gCm⁻², and in tropical waters Turtle grass, Thalassia, may produce 500-1500 gCm⁻² annually. The productivity of mangrove swamps has not been well documented, but appears to be 350-400 gCm⁻².

The report presents information on the seasonal pattern of growth of Laminaria longicruris, L. digitata, and Agarum cribrosum; seasonal variations in photosynthesis and respiration in seaweeds; storage and translocation in seaweeds; growth in Macrocystis pyrifera in southern California; the overall strategies of seaweeds; and production strategies of some other marine macrophytes such as Spartina.

Much of the information is also presented graphically, as well as in the text, and an extensive list of references is included. (B.W.)

Keywords: productivity, grasses, algae, mangrove, macrophytes

II-A-4

Talling, J.F. 1975. Primary production of aquatic plants--conclusions. Pages 281-294 in J.P. Cooper, ed., Photosynthesis and productivity in different environments. Cambridge University Press, London.

This is a summary chapter for the section on primary production in aquatic ecosystems. It contains some useful comparative materials and a bibliography. (J.B.)

Keywords: primary production, aquatic ecosystems

II-A-5

De la Cruz, A.A. 1973. The role of tidal marshes in the productivity of coastal waters. Association of Southeastern Biologists Bulletin 20(4):147-156.

De la Cruz provides an up-to-date and comprehensive discussion of the productivity of coastal marshes and the utilization of detrital materials in the food chain. The article reviews the major conclusions of previous research; enumerates the reasons for the productivity of coastal waters; and discusses primary productivity, plant decomposition, detritus transport, nutritive value of detritus, and consumption in terms of the author's own studies in a marshland on the northwestern side of Bay St. Louis, Mississippi. A number of tables are provided that give comparative figures for primary production, decomposition rate, caloric content, and elemental composition of marsh and estuarine plants on the basis of the findings of previous studies. The article

closes with an excellent list of references that can serve as a starting place for anyone wishing to make a survey of the value of tidal marshes. (J.B.)

Keywords: productivity, detritus, food chain, coastal waters, Mississippi

II-A-6

Odum, E.P. 1961. The role of tidal marshes in estuarine production. The Conservationist 15(June-July):12-15.

This is an excellent, early introduction to the value of coastal marshes that discusses primary production and detritus utilization on the basis of the pioneering studies by the University of Georgia Marine Institute at Sapelo Island. Odum points out that marsh productivity is based on the three separate vegetation regimes: (1) the vast areas of Spartina or cord grass marshes; (2) the benthic or mud algae that grows throughout the intertidal sediments, but especially on the creek banks, and (3) the phytoplankton in the water. Comparisons are made between marsh lands and other land and water areas. Because marsh areas are highly productive, emphasis should be placed on utilization as they are rather than on transformation for other forms of production. Much more needs to be learned about how energy flows in the system, which is extremely complex, partly because the three primary crops produce different consumer energy flows. Because of the great importance of exports and imports and the diversity of production and consumption units, the entire estuarine system must be considered as a whole. The paper emphasizes the need for differential development criteria for high, low, and intermediate marshes. (J.B.)

Keywords: productivity, detritus, coastal marsh, salt marshes value, Georgia

II-A-7

Schelske, C.L., and E.P. Odum. 1962. Mechanisms maintaining high productivity in Georgia estuaries. Proceedings of the Gulf and Caribbean Fisheries Institute 14:75-80.

The productivity of estuaries, as well as the productivity of most ecosystems, is essentially dependent on the rate of primary productivity within the system or, in other words, on the amount of organic material formed as the result of photosynthesis. Heterotrophic organisms, like man, are dependent on green plants for food supply. Therefore, the high productivity of estuaries is really a function of the rate of plant growth.

The results of studies of the extensive, unpolluted estuaries at Sapelo Island, Georgia, indicate that the following factors are responsible for high productivity: (1) ebb-and-flow water movements resulting from tidal action; (2) abundant supplies of nutrients; (3) rapid regeneration and conservation of nutrients due to activity of microorganisms and filter feeders; (4) three types of primary production units (marsh grass, benthic algae, and phytoplankton), which insure maximum utilization of light at all seasons; and (5) year-round production with successive crops. These factors are discussed and illustrated by data obtained by various workers at the University of Georgia Marine Institute. (A.A. and excerpt)

Keywords: estuaries, primary productivity, high productivity factors, Georgia

II-A-8

Keefe, C.W. 1972. Marsh production: a summary of the literature.

University of Texas Contributions in Marine Science 16:163-181.

The paper summarizes the literature on both inland and coastal marsh primary production. Discussions of production measurements, factors influencing marsh production, nutrient content of marsh plants, and energy flow are presented. The author points out that extensive work has been done to determine net primary production and to describe the reasons for high marsh production compared to production in terrestrial communities.

The physical environment of the marsh is used to advantage by the marsh plants. Hybrid vigor, leaf orientation, long growing season, abundant water, and other factors are important for high production. Salt marsh plants support two food webs. The first web is composed of primary consumers that feed on the living marsh plants. The consumers of the second web feed on the plants as detritus, both on the marsh floor and in the estuary. The populations of consumers supported to some extent by detritus are large and would be reduced by almost 50 percent if there were no input of detritus from salt marsh production.

The paper suggests that there is still a great deal of primary research that needs to be done, particularly with respect to the relative contribution of marsh detritus to freshwater ecosystems and to complex salt-water ecosystems of the Chesapeake Bay type. (B.W.)

Keywords: primary productivity, food chain, detritus, marsh plants

II-A-9

Lugo, A.E., and S.C. Snedaker. 1974. The ecology of mangroves. Pages 39-64 in R.F. Johnson ed., Annual review of ecology and systematics, Vol. 5. Annual Reviews, Inc., Palo Alto, California.

This article offers a comprehensive review of studies related to the productivity of mangroves and their utilization in the food chain. The article also covers structural studies and the mangrove ecosystem responses to stress. A table summarizes productivity values derived from the various Floridian and Puerto Rican mangrove studies that are discussed in the text. Ninety-seven works are cited in the list of references., (J.B.)

Keywords: mangrove, productivity, food chain, Florida, Puerto Rico

II-A-10

Walker, R.A. 1973. Wetlands preservation and management on Chesapeake Bay: the role of science in natural resource policy. Coastal Zone Management Journal 1(1):75-101.

There are five primary food sources for estuarine organisms: marsh detritus, phytoplankton, benthic algae, submerged vegetation, detritus from upland sources. The relative importance of these sources varies widely from estuary to estuary and should not be generalized. The popular view of the input value of marshes derives from studies in the warm, shallow, marsh embayments of Georgia. However, in a deeper estuary such as Beaufort Bay, North Carolina, submerged grasses and their attached algae are the dominant production groups. In Chesapeake Bay, unlike either the North Carolina or Georgia study areas, upland drainage is extremely important and marshes are a relatively smaller part of the ecosystem.

Wetlands preservation has become a favorite cause of conservationists. Protection of wetlands is justified primarily on the grounds of their beneficial biological and hydrological effects, so it is to the physical sciences that government and the public turn for the formulation of management policies. However, scientific knowledge cannot be translated directly into good resource policy for society. Despite growing scientific sophistication, man is limited in his ability to understand and to predict the effects of man-induced change on natural systems, especially ones as complex as the Chesapeake Bay and its associated wetlands.

Moreover, an obsession with the exploration of physical processes obscures the more important task of understanding and controlling the social processes that lead man to alter nature. Natural resource

management implies the management of social and economic, as well as natural, systems. (J.B.)

Keywords: coastal marshes, conservation, planning and management, Chesapeake Bay

B. Marsh Grass Productivity Studies

II-B-1

Eilers, H.P., III. 1975. Plants, plant communities, net production and tide levels: the ecological biogeography of the Nehalem salt marshes, Tillamook County, Oregon. Ph.D. Thesis. Oregon State University. 387 pp. (Diss. Abstr. 35:5851-B)

Nehalem Bay is located on the northern coast of Oregon in Tillamook County and contains approximately 243 ha of salt marsh. The Nehalem marshes occur as islands and land-tied units. West Island is the largest marsh island with an area of 82.9 ha and a maximum elevation of 3.079 m above mean lower low water (MLLW). Three divisions on West Island, based on inundation period, have been identified: intertidal marsh, below mean high water (MHW); transitional marsh, from MHW to 2.76 m above MLLW; and extratidal marsh, above 2.76 m. West Island may be further subdivided into four topographic units based on the steepness of the elevation gradient: edge marsh, from the lower margin to 2.00 m; low marsh, 2.00 to 2.36 m; transitional marsh, 2.36 to 2.76 m; and high marsh, 2.76 m and above.

Creek density is low for the lower intertidal marsh for the edge marsh, and for the higher extratidal marsh and is high for the upper intertidal and transitional marsh. Salt marsh vegetation on West Island was sampled by harvesting above-ground biomass along seven transects at two-month intervals from May 1972 to September 1972. Plant species diversity increased with elevation and each species displayed a particular elevation range. Analysis of dry-weight data by an ordination routine suggested the presence of 11 plant communities along the elevation gradient on West Island.

Plant communities named by dominant species are Triglochin, Scirpus, Carex (tall and short phases), Carex-Deschampsia-Triglochin, Triglochin-Deschampsia, Carex-Deschampsia-Triglochin-Agrostis, Juncus-Agrostis, Juncus-Agrostis-Festuca, Aster-Potentilla-Oenanthe, Carex-Aster-Oenanthe, and Picea-Salix. Plant communities are readily identified by signatures on aerial photographs. Net areal production on West Island increased with elevation and varied from a minimum of 518 g/m²/yr for the Triglochin community to a maximum of 1936 g/m²/yr for the Aster-Potentilla-Oenanthe community.

The community mean net areal productivity is $1388 \text{ g/m}^2/\text{yr}$. More than 90 percent of the intertidal marsh net areal production is removed to the estuary as organic detritus, and net areal production in the high marsh is rapidly incorporated into marsh soil. It is estimated that approximately 56 percent of all net areal production on West Island is transported to the estuary by the tides. It is recommended that salt marshes be preserved in their natural state and new salt marshes be created to ensure the continued high productivity of estuarine ecosystems in Oregon. (A.A.)

Keywords: salt marsh, salt marsh plants, biomass, productivity, tidal marsh, Oregon

II-B-2

Mahall, B.E., and R.B. Park. 1976. The ecotone between Spartina foliosa Trin. and Salicornia virginica L. in salt marshes of northern San Francisco Bay. I. Biomass and production. Journal of Ecology 64:421-433.

One of the most striking characteristics of tidal salt-marsh vegetation is its frequent division into distinct zones. Northern San Francisco Bay is an ideal location in which to study salt marsh zonation because of its heavy winter rainfall, uniform soil composition, geographically uniform shoreline, and simple zonation at mean high water (MHW) level between two monospecific communities of Spartina foliosa and Salicornia virginica.

Measurements were made of the standing crop and net production above and below ground in 1972 along two transects: one on the Petaluma River and one on Mare Island. The height of the aboveground standing crop and the net production of Spartina generally decreased landward and decreased greatly at the middle of the ecotone. The height of the aboveground crop and the net production of Salicornia also decreased toward the ecotone, but at Mare Island, Salicornia was more productive per unit biomass in the Spartina zone than in the Salicornia zone.

The authors conclude that there is little competition between the two species at the ecotone and that the primary limitations are physical and physiological. (B.W.)

Keywords: marsh plants, productivity, Spartina, Salicornia virginica, California

II-B-3

Mall, R.E. 1969. Soil-water-salt relationships of waterfowl food plants in the Suisun Marsh of California. California Department of Fish and Game, Wildlife Bulletin No. 1. 39 pp.

This is one of the few studies of the productivity of Pacific Coast marshes. It found a mean value of 722 g m^{-2} for Salicornia virginica, with a reduction to 276 g m^{-2} on highly saline soils. The study also discusses the marsh environment, plant use and selection by waterfowl, and the impact of habitat degradation on waterfowl resources. (J.B.)

Keywords: soil-water-salt relationships, waterfowl, food plants, coastal marsh, California

II-B-4

Kirby, C.J., and J.G. Gosselink. 1976. Primary production in a Louisiana gulf coast Spartina alterniflora marsh. Ecology 57:1052-1059.

Live and dead aboveground biomass of Spartina alterniflora Loisel in a south Louisiana salt marsh in the Barataria Bay estuarine system was determined monthly over an annual cycle. The productivity of streamside and inland marsh areas are compared. This is the first published report of saline marsh production in this vast marsh area and is of interest because of the nearly subtropical conditions and low tidal energy that distinguish gulf coast marshes from Atlantic coast marshes.

Litter bags were used to determine loss rates of particulate vegetation from the marsh surface. Net aboveground primary production estimates ranged from 750 to $2,600 \text{ gm}^{-2} \text{ yr}^{-1}$, depending on how data were handled. Analysis of these results suggested that true net production was probably much closer to the highest estimate than to the lowest. Annual production of an average gulf coast salt marsh was calculated to be $1,176 \text{ g m}^{-2}$. (A.A. and B.W.)

Keywords: Spartina, primary production, biomass, coastal marshes, Louisiana, U.S. Gulf coast

II-B-5

Kirby, C.J. 1971. The annual net primary production and decomposition of the salt marsh grass Spartina alterniflora Loisel. in the Barataria Bay estuary of Louisiana. Ph.D. Thesis. Louisiana State University, Baton Rouge. 73 pp.

The annual net primary production of Spartina alterniflora was determined for both inland and streamside marsh. Production was initially calculated by summation of the monthly changes in standing

crop; however, an alternate method is suggested which measures production as a dynamic process and accounts for certain inherent discrepancies which occur in the initial method. The alternate method, which is termed "true net production," was found nearly to double the production calculated by summation of the monthly change in standing crop. The two methods are compared and discussed.

The rates of decomposition and loss of dead standing Spartina from the marsh were examined by utilizing nylon mesh litterbags. The streamside marsh, inland marsh, and tidal channel were considered in the measurement of loss rates. Dead material was found to decompose most rapidly in the tidal channel.

The decomposition rates of four particle-size fractions of dead Spartina, considered small enough to have been easily washed off the marsh surface, were studied under laboratory conditions. At a constant temperature of 30°C, particles of 111 microns or less were completely decomposed in 30 days, whereas those larger than 111 microns were more slowly affected. (A.A.)

Keywords: primary productivity, Spartina alterniflora, estuary, Louisiana, Barataria Bay

II-B-6

Stowe, W.C., C. Kirby, S. Brkich, and J.G. Gosselink. 1971. Primary production in a small saline lake in Barataria Bay, Louisiana. Louisiana State University Coastal Studies Bulletin No. 6, pp. 27-37.

Production rates of three groups of primary producers (marsh grass, epiphytic algae attached to the marsh grass, and phytoplankton) were studied in a small saline lake. The biggest gap in the information is acknowledged to be examination of benthic and mudflat production. The paper identifies the contribution of each producing group to the total primary production of the lake.

Net production of the marsh grass Spartina alterniflora was estimated by monthly clipping of the aboveground plants with allowances for loss in dead standing crop. Annual production estimates from these samples were found to be 13 percent higher than those reported for the Georgia marsh and 200 percent higher for the inland and 180 percent for the streamside than those reported in a New York salt marsh.

Epiphytes were collected by gathering samples of stems at the water edge and also 5 to 7 feet inland. Summer production was determined by the light-dark bottle method. The figures derived are low compared to those found in California and Florida. Measurements had not yet been taken in winter, but are expected to be higher than summer.

Gross production of phytoplankton was also determined by the light-dark bottle method. Associated chlorophyll curves were found to correlate closely with those reported in 1966 for Pamlico Sound, North Carolina. Calculated gross annual production was 219.8 g C/m^2 . Net annual production, estimated as 90 percent of gross, was 198 g C/m^2 .

Annual production in Airplane Lake was estimated according to the approximate area that each producer occupied and its annual production rate. (G.S., expansion of author's abstract)

Keywords: primary productivity, grasses, algae, phytoplankton, Spartina alterniflora, Louisiana, Barataria Bay

II-B-7

Day, J.W., W.G. Smith, P.R. Wagner, and W.C. Stowe. 1973. Community structure and carbon budget of a salt marsh and shallow bay estuarine system in Louisiana. Louisiana State University Center for Wetland Resources Publication No. LSU-SG-72-04. 80 pp.

The coastal zone of Louisiana includes more than seven million acres of marshes and estuaries. This paper is a description of Barataria Bay, one of the estuaries in the coastal zone. The salt marsh, water column, and benthic communities are each divided into several subunits. Each of these components is treated in terms of seasonal and spatial variations of abundance, feeding habits, life histories, trophic position, and commercial importance. A carbon budget is presented for each of the components and for the whole marsh-estuarine community.

The marsh is dominated by Spartina alterniflora. Net production of the grass is $2,960 \text{ g dry wt/m}^2/\text{yr}$ streamside and $1,484 \text{ g dry wt/m}^2/\text{yr}$ 50 meters inland. The highest rates of production of Spartina occur in late spring. There is a peak of detritus loss from the marsh in the spring, which coincides with rising temperatures and water levels. Phytoplankton dominate primary production during the warmer months, and benthic producers dominate during the colder months. The most numerous and important of the primary producers are diatoms, with macrophytes and other phytoplankton being of lesser importance. Total production is highest during the summer.

The article discusses the fauna of the marsh community, which is composed largely of detrital feeders, including most of the meiobenthos, crabs, snails, mussels, and many of the insects. Several species are discussed in some detail because of their commercial importance.

From the studies of the different components of the estuary, the authors constructed a budget of the entire estuary. Production and

flow of organic matter and energy flow are presented in diagram, as well as in the text. (B.W.)

Keywords: salt marshes, primary productivity, Spartina alterniflora, marsh fauna

II-B-8

Payonk, P.I. 1975. The response of three species of marsh macrophytes to artificial enrichment at Dulac, Louisiana. M.S. Thesis. Louisiana State University, Baton Rouge, Louisiana. 121 pp.

Populations of three species of macrophytic vegetation in a freshwater marsh near Dulac, Louisiana, were treated between April 1974 and January 1975 with wastewater from a menhaden processing plant. The wastewater significantly increased the net aboveground primary production of Sagittaria falcata, Scirpus validus, and Spartina patens. Production for S. falcata was $918 \text{ g m}^{-2}\text{yr}^{-1}$ for the experimental population as compared to $608 \text{ g m}^{-2}\text{yr}^{-1}$ for the control (a 51 percent increase); similar data for S. validus were $1804 \text{ g m}^{-2}\text{yr}^{-1}$ compared to $1260 \text{ g m}^{-2}\text{yr}^{-1}$ (a 43 percent increase). Data for S. patens were $2939 \text{ g m}^{-2}\text{yr}^{-1}$ compared to $2128 \text{ g m}^{-2}\text{yr}^{-1}$ (a 38 percent increase).

Differences between the experimental and control mean content of nitrogen and phosphorus in the plant tissues were used to estimate the proportion of applied nutrients actually incorporated into the plant tissues. S. falcata incorporated 4.6 percent of the nitrogen and 4.0 percent of the phosphorus applied to the plant tissues. S. validus incorporated 3.4 percent of the nitrogen and 4.0 percent of the phosphorus. S. patens incorporated 4.1 percent and 7.4 percent of the waste nitrogen and phosphorus, respectively.

Concentrations of nitrogen and phosphorus in the marsh surface water were increased by the additions of the wastewater. Measured increases in nitrogen and phosphorus concentrations accounted for 12 percent and 16 percent, respectively, of these nutrients added through wastewater enrichment. The remainder of the added nutrients probably was deposited into the marsh soil system or escaped from the area through limited flushing action. (A.A.)

Keywords: marsh plants, macrophytes, freshwater marsh, nutrients, productivity, Louisiana

II-B-9

Eleuterius, L.N. 1972. The marshes of Mississippi. Castanea 37:153-168.

Mississippi has a shorter coastline than any other state bordering the Gulf of Mexico. In the past few years, the marshes have come under

increasing pressure from industrial and suburban developments and they have been widely used as garbage dumps. In view of future plans, it is imperative that the marshes be thoroughly studied ecologically and their value assessed on productivity as part of the coastal ecosystem. Their economic value is far-reaching and intermeshed with the commercial fisheries, as well as recreational aspects of south Mississippi. Some people find the marshes of aesthetic value and a place to refresh themselves. An initial study was conducted in 1968 and 1969 to determine the composition, area, zonation, organic production, and some of the regulating factors influencing the marsh vegetation. A summary of the observations and conclusions is presented in this paper.

Mississippi marshes were sampled during 1968 and 1969 by line transect and list count quadrats, and the composition of vascular plants throughout the salinity gradient was determined in three estuarine systems. Profile diagrams were prepared to illustrate lateral zonation of the plant communities. Marsh acreage, measured by planimeter from survey maps, was determined. Organic production of the vascular marsh plants in Mississippi was estimated. Present and projected manmade changes in the marshes are discussed. Some observations on composition and zonation of plant colonization on spoilbanks and landfills are presented.

The paper is especially relevant to marsh productivity. It discusses plant species and their distribution in relation to salinity; dominant plant species; the grass-rush-sedge complex; regions of the marsh; and composition of saline, brackish, intermediate, and freshwater marshes. Other headings deal with zonation of the marsh, acreage and production, dredge and fill operations and plant colonization. An overall discussion sums up production estimates and concludes that "the role of marshes in an estuary are many and varied. Biological, chemical and physical systems interact in complex fashions, and these are generally poorly understood. One of the key roles of marsh vegetation is the converting of inorganic compounds, water and sunlight, into plant tissues which can be utilized by consumer organisms in the marsh and open waters of the estuary. The marshes also serve as protective habitats for astronomical numbers of animal organisms." (G.S.)

Keywords: salt marshes, productivity, Mississippi

II-B-10

De la Cruz, A.A. 1974. Primary productivity of coastal marshes in Mississippi. Gulf Research Reports 4:351-356.

Coastal marshes are commonly characterized as sites of extremely high primary production. The author contends that the available data are insufficient to support or refute such a generalization. It is more likely that marshes differ considerably in their productivity. The diverse nature of marshlands along the Gulf Coast of Mississippi

offers an ideal opportunity to test differences in the primary productivity of different species of marsh plants. The irregularly flooded marsh dominated by Juncus roemerianus, waterlogged salt flats of Distichlis spicata, and salt meadows of Spartina patens are found in Mississippi coastal estuaries. Mixed stands for several marsh plant species are common. As many as 34 species may be found in one locality although only a few of these are of major importance.

Primary production studies in the northern Gulf of Mexico marshes are few. Kirby (1971) reported an annual net production of 1006-1410 g m⁻² for an S. alterniflora marsh in Louisiana. Eleuterius (1972) estimated production value of about 2000 g m⁻² yr⁻¹ for a J. roemerianus marsh in Mississippi. More recently an initial study on a mixed vegetation marsh at St. Louis Bay estuary in Mississippi showed production value of 1100 g m⁻² yr⁻¹ (Gabriel and De la Cruz 1974). In all these studies, only the annual net primary productivity of aboveground materials was measured.

The annual net primary production of nine types of marsh communities common in Mississippi Gulf coast estuaries was studied by means of the Harvest Method. Production values ranged from 600 g m⁻² yr⁻¹ for a Sagittaria lancifolia marsh to 2,330 g m⁻² yr⁻¹ for a Phragmites communis marsh. Primary productivity values for the other marsh types are:

<u>Marsh Type</u>	<u>Productivity</u>
<u>Juncus roemerianus</u>	1,697 g m ⁻² yr ⁻¹
<u>Scirpus robustus</u>	1,056 g m ⁻² yr ⁻¹
<u>Spartina cynosuroides</u>	2,190 g m ⁻² yr ⁻¹
<u>Spartina patens</u>	1,922 g m ⁻² yr ⁻¹
<u>Spartina alterniflora</u> tall form	1,964 g m ⁻² yr ⁻¹
<u>S. alterniflora</u> short form	1,089 g m ⁻² yr ⁻¹
<u>Distichlis spicata</u>	1,484 g m ⁻² yr ⁻¹

Annual net productivity in Mississippi marshes is generally slightly higher than that reported for the Atlantic marshes. (A.A. and introduction)

Keywords: primary productivity, marsh plants, coastal marshes, Mississippi

II-B-11

Gabriel, B.C., and A.A. de la Cruz. 1974. Species composition, standing stock, and net primary production of a salt marsh community in Mississippi. Chesapeake Science 15:72-77.

Along the Gulf Coast and on barrier islands of Mississippi are some 27,000 hectares of verdant marshlands. These marshes generally consist

of mixed species of grasses, rushes, and sedges and may be categorized as salt flat, salt meadow, and irregularly flooded salt marsh communities. The regularly flooded Spartina alterniflora marsh common in the south Atlantic coast and in the Louisiana deltas occurs in Mississippi in rather limited patches, forming a narrow discontinuous band in the low tide zones of river mouth banks and certain exposed beaches fronting the Mississippi Sound. Except for one report on the primary production of Juncus roemerianus marsh, there had not been any productivity studies on the Mississippi marshes until this one was conducted.

In this study, square-meter quadrat samples harvested monthly during 1971 to 1972 provided data on the species composition, standing stock, and net primary aerial production of a salt marsh community in St. Louis Bay Estuary, Mississippi. Although a total of 34 species of marsh plants were identified, Juncus roemerianus, Spartina cynosuroides, Scirpus americanus and Distichlis spicata were found to be the most dominant in all the quadrats sampled. Maximum biomass of alive, dead, and partially decayed plants was observed in July, August and January, respectively. Total biomass obtained by reharvesting previously clipped quadrats in various ages of regrowth revealed a seasonal pattern of growth rate with a maximum during late summer. (G.S.)

Keywords: primary productivity, Spartina, salt marshes, Mississippi

II-B-12

Odum, E.P., and M.E. Fanning. 1973. Comparison of the productivity of Spartina alterniflora and Spartina cynosuroides in Georgia coastal marshes. Bulletin of the Georgia Academy of Science 31(1):1-12.

The purpose of this paper is to compare the net primary production of the salt marsh Spartina alterniflora with the fresh or brackish marsh Spartina cynosuroides in an optimum habitat for each; or, in other words, to compare production in areas where each species grows most vigorously. The general theory being tested was that given a favorable tidal irrigation "energy subsidy," stands of S. alterniflora would be able to equal or exceed the primary production of stands of S. cynosuroides.

As a result of the research, net production of S. alterniflora was estimated to be two to three times that of S. cynosuroides. The paper further determined that the productivity of S. alterniflora can be very high under conditions of high salinity, exceeding that of a related species growing in fresh water, wherever there is abundant, daily tidal flow. Thus, the paper concluded that such tidal action does provide an "energy subsidy" that reduces the metabolic cost of coping with the stressful environment. In this sense, salt marshes in Georgia convert "tidal power" into organic food. (L.H.)

Keywords: primary productivity, Spartina alterniflora, Georgia

II-B-13

Smalley, A.E. 1959. The growth cycle of Spartina and its relation to the insect populations in the marsh. Pages 96-100 in Proceedings of the salt marsh conference, Sapelo Island, Georgia. University of Georgia, Athens.

Spartina alterniflora Loisel is the dominant spermatophyte of the marshes around Sapelo Island, Georgia, usually occurring in pure stands of varying height and density. A previous study took clip samples at frequent intervals throughout the year in streamside marshes (the area of highest production). This study used the same technique in the relatively low production areas of high marshes. Net production was computed from the between-sample increases in the living, standing crops and changes in dead standing crops (the latter providing a partial estimate of grass which died in the interval between samples). The estimate of the average annual net production of the entire marsh was 973 grams dry matter per square meter or 4248 kilogram calories/m² based on estimates of production of each marsh type in proportion to the area occupied by each as determined from aerial photos.

The pattern of Spartina distribution revealed by standing crop measurements suggests that the organisms that depend on the grass as a nutrient source fall into two categories. The first are those that feed on the living, growing grass. The second are those that utilize the grass after it has died, whether it remains in the marsh or is washed out into the surrounding waters. The latter group must consist largely of microorganisms. The decomposed and fragmented grass forms part of the detritus of the marsh-estuarine complex and in this form may enter the marsh again when the marsh is flooded by the surrounding waters.

Observations and collections on the marsh show that the most important herbivores feeding on living Spartina are two species of insects. One is a grasshopper, Orchelimum fidicinum Rehn and Hebard (Orthoptera: Tettigoniidae), occurring from May to September; the other, a leafhopper, Prokelesia marginata Van Duzee (Homoptera: Fulgoridae), which occurs the year round, but is most common in winter. These two major herbivores were found to assimilate only 7 percent of the annual net production of grass. In comparison, the "utilization efficiency" of herbivores was shown to be 38 percent in a spring community and as high as 81 percent in a marine zooplankton-phytoplankton system in the English Channel. It is suggested that a tidal marsh is similar to a forest in its trophic structure at the herbivore level, since in either case immediate consumption of the primary photosynthetic product is of less importance than its subsequent utilization and decomposition by detritus feeders and microorganisms. Discussion appears following presentation of the paper. (G.S.)

Keywords: Spartina, salt marsh, primary production, Georgia

II-B-14

McIntire, G.L., and W.M. Dunstan. 1975. The seasonal cycle of growth and production in three salt marshes adjacent to the Savannah River. Skidaway Institute of Oceanography, Savannah, Georgia, Technical Report No. 75-2. 19 pp.

Three geographically similar Spartina alterniflora marshes near Savannah, Georgia, were studied monthly during 1974. Production levels, percent ash, and other growth parameters were measured. While general growth trends were similar at all three sites, the levels of production varied significantly, with the marsh on the Savannah River showing the greatest production. Measurements of standing dead Spartina revealed a ready supply of detrital energy which is available to the adjacent estuarine regions throughout the year. The Savannah River marsh demonstrated that studies of river systems with high levels of industrial municipal effluents must consider increased plant production as well as inhibitory or toxic effects. The study is a first step toward a "condition index" for coastal salt marshes that would enable industrial and governmental agencies to determine the effects of environmental perturbations on these important natural resources. (A.A.)

Keywords: primary productivity, Spartina, salt marshes, Georgia

II-B-15

Gallagher, J.L., R.J. Reimold, and D.E. Thompson. 1972. Remote sensing and salt marsh productivity. Photogrammetric Engineering 38:591. (Abstr.)

The feasibility of using photography or thermal imagery from fixed-wing aircraft for assessing salt marsh productivity is being investigated. Kodak Aerochrome Infrared 2443 and Aerocolor Negative 2445 films and a Bendix Thermal Mapper are being used. Remote sensing flights (from 1,250 to 20,000 feet) are made in conjunction with acquisition of ground-truth data consisting of chlorophyll per unit area, the density of living and dead plants by number, and biomass for each species and each one-half meter height class.

A number of windows in the 2 to 13 micrometer wavelength range are being tested with the thermal mapper to ascertain which gives the best discrimination of spatial productivity patterns. Color enhancement of the imagery has proven useful in defining the extent of these areas and predicting tidal hydrography in the intertidal zone.

Color patterns in the color-infrared photographs, due in part to differences in plant species, density, growth form, and pigmentation, are being quantified by: (1) planimetry of handdrawn visual interpretation of projected transparencies; (2) planimetry of visual interpretation using a Kernplotter; and (3) microdensitometry of each zone defined by a Joyce Loebble Microdensitometer coupled with a four-color isodensitracer.

Photographs are used to predict productivity at untested locations within the study areas, and ground-truth is collected at these sites during subsequent sampling periods.

Annual Spartina alterniflora above-ground production (g dry wt m⁻²) of a salt marsh in Georgia was determined:

Infrared Imagery	End of Season Live	End of Season Dead	End of Season Total
Red	1665	301	1966
Light-red	630	169	799
Blue-red	499	226	725
Blue	331	57	388
Marsh Average	781	188	969
Juncus (net)	913	625	1538

(Gallagher's data as reported by Turner 1976)

(B.W.)

Keywords: salt marshes, productivity, remote sensing, biomass, Georgia

II-B-16

Williams, R.B., and M.B. Murdoch. 1969. Annual production of Spartina alterniflora and Juncus roemerianus in salt marshes near Beaufort, North Carolina. The Association of Southeastern Biologists Bulletin 12:49. (Abstr.)

The production of organic matter by salt marsh phanerogams, Spartina alterniflora and Juncus roemerianus, was studied in areas near Beaufort, N.C. Living and dead plants were removed from 1 m² quadrats at 5-week intervals, sorted, dried and weighed. Production was calculated by adding an estimate of the quantity of material produced and lost prior to harvest to the measured standing crop of living plants. In September, the end of the main growing season, standing crops of the live Spartina ranged from 0.25 kg (dry weight)/m² in the high marsh to 2.1 kg/m² in the streamside marsh. Average annual production for Spartina was ca. 1 kg/m². Both the maximum standing crop and the annual production of Juncus were also ca. 1 kg/m². From this rate of production and the quantities of dead plant material in the marsh, the daily loss of dead Spartina was estimated to average 1 percent of its total weight, and of dead Juncus, a fraction of 1 percent. (A.A.)

Keywords: food chain, Spartina alterniflora, Juncus roemerianus, salt marsh, North Carolina

II-B-17

Williams, R.B. and M.B. Murdoch. 1972. Compartmental analysis of the production of Juncus roemerianus in a North Carolina salt marsh. Chesapeake Science 13:69-79.

Juncus roemerianus (needlerush) grows in the upper intertidal zone of salt marshes and covers extensive areas along the shore of North Carolina and elsewhere along the southeastern seaboard. Other species of Juncus are important components of salt-marsh florae elsewhere in the world. As part of a study of total plant production in the estuarine areas adjoining Beaufort, N.C., the authors endeavored to measure the annual aboveground production of a nearly pure stand of Juncus roemerianus. First the standing crop was followed for a year by harvesting quadrats of Juncus. When it became obvious that there were no pronounced seasonal cycles in production, the growth and longevity of individual leaves was followed for nearly 2 years. These data (obtained near Cape Lookout, North Carolina during 1965 to 1968 on standing crop, growth rate, and longevity of above-ground portions of needlerush) were synthesized into a three-compartment linear mathematical model. Analysis of field observations yielded average standing crops for live, dying and dead Juncus of 344, 504, and 1,604 g dry wt m⁻², respectively, and an annual production of 754 g dry wt m⁻². The model duplicated the average standing crops and annual production; it also yielded seasonal cycles in the standing crops of the three compartments, these cycles explaining much of the variations observed during the field work.

The seasonal changes in standing crop observed were generally similar to those reported previously. Stroud and Cooper (1968) and Waits (1967) also found the proportion of dead material least in the summer and greatest in the winter. In all three studies the proportion of living material had, of course, a reverse cycle. Foster (1968) reported that the number per square meter of green and brown leaves was greatest in the summer and least in the winter. These results agreed with the author's observations on the seasonal cycle in biomass in the dying compartment. Foster's observations on the number of green leaves indicated, however, a seasonal cycle with a maximum in midsummer, whereas the reported seasonal cycle in biomass had its maximum in the fall. This lack of agreement reflected different in methods. (G.S.)

Keywords: Juncus roemerianus, salt marsh, needlerush, North Carolina

II-B-18

Waits, E.D. 1967. Net primary production of an irregularly flooded North Carolina salt marsh. Ph.D. Thesis. North Carolina State University at Raleigh. 124 pp. (Diss. Abstr. 28:4027-B)

The major vegetation types of an irregularly flooded salt marsh on the Outer Banks of North Carolina were defined by analyzing species presence data obtained from sample plots. Six vegetation types were described

in this marsh. Detailed information on the composition and structure of four of these vegetation types, Spartina patens, mixed, Juncus roemerianus, and marginal types, are presented. These vegetation types are distinguishable in species composition or varying importance of certain species and in certain habitat factors. Several habitat factors of the marsh were studied. Information is presented on depth and salinity of standing water, depth of peat layers, particle size distribution of the sand substrate, elevations, and tidal fluctuation.

The primary purpose of this investigation was to obtain estimates of the net primary production of the major vascular plant species in an irregularly flooded salt marsh. A harvest method was used to obtain standing crop estimates of the major species for a two-year period. These standing crop values were used to calculate net production. Net production was calculated using two methods. The first method involved the use of only the living standing crop estimates. Since this method produced underestimates of net production, a second method was used that took into account changes in both the living and dead standing crops. Both of these methods were applied to observed mean standing crops and to predicted standing crop values obtained by fitting the observed data to a fourth degree polynomial in time. The observed standing crop values were fitted to the polynomial in an attempt to obtain a better description of the growth of the major species over time. The fit of the data to the polynomial was reasonably good for most species.

The net primary production estimates obtained indicate that the irregularly flooded marsh studied is not so productive, when considered on a whole-marsh basis, as regularly flooded salt marshes. However, the data collected in this study, which are comparable to that collected for regularly flooded marshes, indicate that certain vegetation types in the irregularly flooded marsh (Spartina patens, mixed and Juncus roemerianus types) are considerably more productive than short Spartina alterniflora in regularly flooded marshes. None of the vegetation types in the irregularly flooded marsh were as productive as the levee-streamside (medium and tall) Spartina alterniflora of regularly flooded marshes. (A.A.)

Keywords: primary productivity, salt marsh, Spartina, Juncus, North Carolina

II-B-19

Williams, R.B., and M.B. Murdoch. 1969. The potential importance of Spartina alterniflora in conveying zinc, manganese and iron into estuarine food chains. Pages 431-439 in D.J. Nelson, ed., Proceedings of the Second National Symposium on Radioecology. U.S. Atomic Energy Commission, Washington, D.C.

The potential importance of cord grass in conveying radioisotopes of zinc, manganese, and iron into estuarine food chains was evaluated on the basis of its annual production, its content of these elements,

and its annual cycle of growth and decay. The growth of Spartina was studied with harvest and other techniques in salt marshes near Beaufort, N. C. Standing crop at maturity (in the fall) and annual production were estimated to average 545 to 650 g dry wt/m², or 208 and 248 g C/m², respectively. Spartina production approached one-third the total phytoplankton net production of adjacent estuaries, and thus was potentially important in estuarine food chains. Zinc, manganese, and iron all had markedly higher concentrations in dead Spartina than in live, and averaged 22, 200, and 5000 ppm (dry wt), respectively, in the dead material. The unusually high iron content of the dead material suggested that the Spartina detritus may be especially important in the movement of radioisotopes of iron from water and sediment into estuarine animal populations. (L.H.)

Keywords: food chain, minerals, Spartina alterniflora, North Carolina

II-B-20

Stroud, L.M., and A.W. Cooper. 1968. Color-infrared aerial photographic interpretation and net primary productivity of a regularly-flooded North Carolina saltmarsh. North Carolina Water Resources Research Institute Report No. 14, North Carolina State University, Raleigh. 86 pp.

A study was made of the net primary productivity of salt marsh communities in a 2000-acre, regularly flooded marsh in Brunswick County, N. C. Color infrared aerial photographs were used to determine acreages of community types. Acreages were: short Spartina alterniflora (cordgrass) - 837; medium cordgrass - 195; tall cordgrass - 110; Juncus roemerianus (black needlerush) - 161; water - 474; other - 118. Net primary productivity estimates were based on harvest method data. Observed harvest data were fitted to a fourth-degree polynomial in time in order to express the average behavior of the standing crop through the year. Net productivity was determined by two methods: (1) use of living standing crop only, and (2) use of changes in living and dead standing crop. Estimates of net primary productivity using changes in living and dead standing crops based on the prediction equation were: short cordgrass - 1106 kcal/m²/yr; medium cordgrass 1856 kcal/m²/yr; tall cordgrass - 6471 kcal/m²/yr; black needlerush - 5346 kcal/m²/yr. Over the entire marsh net primary productivity was estimated to be 1534 kcal/m²/yr. These values were lower than similar values from Georgia, but were close to other estimates of net primary productivity for salt marsh vascular plants in North Carolina. (A.A.)

Keywords: primary productivity, infrared photography, Spartina alterniflora, Juncus roemerianus, North Carolina

II-B-21

Foster, W.A. 1968. Studies on the distribution and growth of Juncus roemerianus in southeastern Brunswick County, North Carolina. M.S. Thesis. North Carolina State University at Raleigh. 72 pp.

The distribution of Juncus roemerianus (needle rush) relative to other marsh plant species along a composite environmental gradient represented by a river marsh was investigated through the use of color infrared aerial photographs. Due to the limited habitat data collected, the factors limiting the distribution of this plant were not determined. However, regions of the marsh where future studies would be most profitable were identified.

Attempts were made to clarify the pattern of growth of needle rush and to determine the rates of growth and death of leaves by measuring the heights of individual leaves. At any given time of year, the shorter, younger leaves grew faster than the taller, older ones. The older a leaf, the greater was its rate of die-back. Most of the die-back occurred after the leaves reached their maximum heights. Growth occurred throughout the year, with the maximum rates occurring in May and June. The rates of die-back were moderate throughout the year, but were highest from July through September. The overall rate of die-back probably exceeded the rate of growth from July through January.

Data from clip plots indicated that both the mean height of mature leaves and the distribution of leaf size remained essentially the same throughout the year. Net leaf productivity for the study area, in terms of dry weight, was estimated to have been 560 g/m²/year. This figure was calculated by combining values for rates of growth and die-back of leaves with values for leaf density and leaf weight. (A.A.)

Keywords: Juncus, needle rush, infrared photography, marsh plants, productivity, North Carolina

II-B-22

Marshall, D.E. 1970. Characteristics of Spartina marsh which is receiving treated municipal sewage wastes. Pages 317-358 in H.T. Odum and A.F. Chestnut, eds., Studies of marine estuarine ecosystems developing with treated sewage wastes. Institute of Marine Sciences, University of North Carolina. Annual Report for 1969-1970.

As populations and development grow along marine coasts, more and more treated sewage effluents enter the marshes and estuaries. One of the main types of ecosystems receiving these wastes is the Spartina salt marsh. A study was conducted on Calico Creek Marsh, near Morehead City, North Carolina.

The estuary, which normally received little fresh water inflow, had a broad area of salt marsh consisting almost entirely of Spartina alterniflora Loisel., and supporting populations of crabs (Uca pugnax, U. pugilator, U. minax, Callinectes sapidus, Sesarma reticulatum), a mussel (Modiolus demissus), and snails (Littorina irrorata and Melampus bidentatus). Clapper rails, sora rails, diamondback terrapin, raccoons, herons, and many shorebirds were also members of the ecosystem.

The plan of the study was to compare a fertilized salt marsh with a natural one throughout an annual cycle. The ability of Spartina to grow in waters receiving treated wastes was also studied. The results showed that the treated marsh produced significantly greater weights of Spartina per square meter. Snail populations were as great or greater in the waste system than in the control system. The author cautions, however, that the effect of fertilization on and contribution to underwater communities was not studied.

Annual Spartina alterniflora above-ground production (g dry wt/m⁻²) was determined:

Marsh Type	End of Season Live	End of Season Dead	End of Season Total
Control:			
Short	410	380	790
Medium	680	400	1080
Tall	1450	600	2050
Average	550	390	
Wastes Added:			
Short	730	300	1030
Medium	870	250	1120
Tall	1970	720	2690 (B.W.)

Keywords: Spartina, salt marsh, nutrients, marsh ecosystem, productivity
North Carolina

II-B-23

Stroud, L.M. 1976. Net primary production of belowground material and carbohydrate patterns of two height forms of Spartina alterniflora in two North Carolina marshes. Ph.D. Thesis. North Carolina State University at Raleigh. 146 pp. (Diss. Abstr. 37:2645-46-B.)

Seasonal patterns, based on monthly samples, in net belowground production, caloric content, and carbohydrate composition were determined for living roots, living rhizomes, and total living material of short and tall height forms of Spartina alterniflora growing at two marshes in North Carolina. An estimate was also made of both dead and total

belowground material. The amount of dead material was correlated with the height form and the age of the marsh.

The root-rhizome/shoot ratios were similar within height forms between both marshes. However, the short height form of S. alterniflora had a greater root-rhizome/shoot ratio than the tall height form.

Net belowground production was calculated by two methods: from the mean living belowground material, and by determining the difference between the maximum and minimum living belowground material. With the first method it was found that root production differed significantly between the short and tall height forms both within the two marshes and between the marshes. Rhizome production in the short and tall forms varied significantly between the two marshes but not within the marshes. Estimates of total mean living belowground production in the short height form differed significantly between marsh locations. Minimal estimates of net production for mean living belowground material (g/m^2) were: Ocracoke, short - 246; Ocracoke, tall - 313; Oak Island, short - 415; Oak Island, tall - 356.

When maximum minus minimum living belowground production estimates were calculated, root production of the short form of S. alterniflora varied significantly between the two marshes. No significant differences were found in root production of tall S. alterniflora between the two marshes. Within the marshes there were no significant differences between the short and tall forms in net primary production of roots at Ocracoke but significant differences were observed at Oak Island. Rhizome production did not differ significantly between the two marshes. Estimates of net belowground production based on the mean maximum minus the mean minimum living material (g/m^2) were: Ocracoke, short - 309; Ocracoke, tall - 301; Oak Island, short - 390; Oak Island, tall - 325.

No significant variation was observed in rhizomes between height forms at Ocracoke but variation existed at Oak Island. Rhizomes also varied significantly between and within height forms between marshes. Root and rhizomes varied significantly within the short height form only at Oak Island. The mean caloric values (g cal/g dry wt) of roots were: Ocracoke, short - 3873; Ocracoke, tall - 3891; Oak Island, short - 3928; Oak Island, tall - 3983. In rhizomes, the caloric values were: Ocracoke, short - 3801; Ocracoke, tall - 3814; Oak Island, short - 4009; Oak Island, tall - 3931.

The carbohydrates were separated into the following fractions: total sugars, reducing sugars, non-reducing sugars (by difference), and storage carbohydrates. The sample means (months) in the carbohydrate components of living roots, rhizomes, shoots, and floral parts showed significant variation within the two height forms both within the marshes and between the marshes.

More variability was found in the carbohydrate composition, particularly non-reducing sugars, of rhizomes than the other plant parts. Most of the carbohydrates in S. alterniflora were found in the non-reducing sugar fraction; therefore, this fraction was largely responsible for the variability in the total sugar component of the tissues. Storage carbohydrates were found in small amounts only in the rhizomes and floral parts.

Differences in carbohydrate composition were observed in all parts of the short and tall forms of S. alterniflora both within and between the marshes. Seasonal patterns in carbohydrate composition were related to phenophase events in vegetative growth, reproduction, and senescence in the life cycle of S. alterniflora. The development of ecophenal extremes in the two height forms in the two marshes also influenced the annual patterns in carbohydrate composition. Differences in the initiation and duration of the primary period of growth at the two marshes due to differential environments also had an effect on the seasonal carbohydrate patterns. (A.A.)

Keywords: primary productivity, Spartina, coastal marsh, North Carolina

II-B-24

Mendelssohn, I.A., and K.L. Marcellus. 1976. Angiosperm production of three Virginia marshes in various salinity and soil nutrient regimes. Chesapeake Science 17:15-23.

The net aerial angiosperm productivity, salinity, and soil nutrient composition of three Virginia marshes were determined. Oligohaline Ware Creek Marsh and mesohaline Carter Creek Marsh were most productive, while euhaline Wachapreague Marsh was least productive. Species in Carter and Ware Creek Marshes were clustered into associations based on salinity tolerance. Nitrogen and phosphorus concentrations of Spartina alterniflora tissue were high in the spring and decreased as the growing season continued. Soil nutrient concentrations were variable, and trends during the growing season were not discernible. No significant correlations were found between soil and plant nutrient concentrations. Although the empirical data suggest that high soil salinity and low soil nitrogen and phosphorus concentrations limited primary productivity in Wachapreague Marsh, a multiple regression of standing crop on these parameters did not delineate any as the primary factors limiting salt marsh production.

While the majority of research has centered on the descriptive ecology and productivity of salt marshes, studies investigating the essential factors limiting salt marsh macrophytic production have only recently been initiated. Some of the factors that most probably

govern this production are: (1) tidal submergence, (2) marsh physiography, (3) climatic conditions, (4) salinity, and (5) soil nutrient concentrations. (A.A.-modified)

Keywords: primary productivity, salinity, soil composition, salt marsh, Virginia

II-B-25

Wise, E.A. 1970. A study of energy fixation and net production of plant communities in salt marshes of Back River, Virginia. Ph.D. Thesis, University of Illinois at Urbana-Champaign.

This study concerned salt marsh community types along Back River, Virginia, an estuary off lower Chesapeake Bay. Intertidal communities were flooded twice daily, while high marsh communities were intermittently flooded. Mean salinity of tidal waters was about 60 percent that of sea water. Salinity conditions at all sites studied fell within the range of adaptation of all species in the marsh.

High marsh community types were distributed in a mosaic pattern, with length of inundation being the major controlling factor. Spartina alterniflora, tall, was found only in the intertidal zone and occurred in pure stands. Community types found on the most frequently inundated sites in the high marsh were Spartina alterniflora, dwarf form, Juncus roemerianus, and Distichlis spicata. Iva frutescens and Spartina patens community types occupied the best-drained sites. Salicornia europaea and Spartina patens-Distichlis spicata community types were frequently inundated.

In certain high marsh communities, there were changes in percentage composition by species during the study, with submergence-tolerant species being replaced by those less tolerant of submergence. This appeared to indicate accumulation and aggradation. Mean organic matter content of the substrate was lowest under Spartina alterniflora, tall, and highest under Spartina patens.

Net primary production per unit area by community types in 1966 was, from high to low: Juncus roemerianus, Distichlis spicata, Spartina patens, Spartina patens-Distichlis spicata, Spartina alterniflora, tall, mixed, Spartina alterniflora, dwarf form, Salicornia europaea, and Atriplex patula. For 1967 the order was Juncus roemerianus, Iva frutescens (added in 1967), Distichlis spicata, Spartina alterniflora, tall, Spartina patens-Distichlis spicata, Spartina patens, Spartina alterniflora, dwarf form, mixed, Atriplex patula-Iva frutescens, and Salicornia europaea. Part of the Spartina alterniflora, tall, and the mixed community types was removed by wave and tidal action before maturity.

Efficiency of conversion of incoming solar energy to biomass, based on indicated peak net primary production, ranged from a high of 0.67 percent for the Iva frutescens community type to a low of 0.17 percent for Salicornia europaea.

In decomposition tests, about 83 percent of Spartina alterniflora, tall, decomposed the first year. Other species, except where amounts were 10 grams or less, were not 83 percent decomposed after 2 years.

Chlorophyll production did not correlate with net primary production of any community type, based on samples taken at or just before the peak of standing crop. Chlorophyll loss was marked when high marsh community types were submerged for extended periods.

Protein content, based on an analysis of individual species, was highest for forbes, lower for Juncus, and lowest for grasses.

Fertilization of stands of Spartina patens and Spartina patens-Distichlis spicata with nitrogen gave increases in net production, chlorophyll, and protein content. There was no response to fertilization with potassium.

Experiments were conducted to determine the effect of salinity on new root production of Spartina patens and Distichlis spicata. Plugs of these species removed from the marsh and treated with full-strength synthetic sea water had less new root production than those treated with half-strength or with tap water used as a control. Under all treatments most new roots originated near the tops of the plugs despite the greater moisture and temperature stress there.

The importance of the salt marshes as producers in the estuarine ecosystem was pointed out. Comparisons of production with other Atlantic coastal salt marshes and with prairies were made. (A.A.)

Keywords: intertidal plant communities, Spartina, Juncus, Salicornia, primary production, energy fixation, Virginia

II-B-26

Keefe, C.W., and W.R. Boynton. 1973. Standing crop of salt marshes surrounding Chincoteague Bay, Maryland-Virginia. Chesapeake Science 14:117-123.

The purpose of the study was to determine the standing crop and chemical composition of the high and low salt-marsh vegetation of Chincoteague Bay, the largest of a series of shallow embayments along the Delmarva peninsula of the Atlantic Coast. Approximately 23,000 acres of salt marsh form a nearly continuous border between dry land and the open waters of the bay. Most of the marsh is flooded by

spring tides and storms, but not by daily lunar tides. The vegetation is dominated by short Spartina alterniflora with Distichlis spicata and Salicornia spp. present in small numbers. Small areas of typical low marsh, dominated by tall S. alterniflora, exist near the inlets and in a narrow band along the bay shore subject to regular flooding.

The estimates of maximum standing crop of dry material and organic matter were recorded based on the results of sampling in August. The greatest variability was in the samples of short Spartina alterniflora, with a minor contribution by tall S. alterniflora. Generally, production per unit of various species decreases from south to north along the Atlantic Coast. Marsh plants from areas in which there were large standing crops had the same percentage composition as plants from areas with small standing crops, indicating that the inorganic nutrients measured were probably not limiting production. (L.H.)

Keywords: primary productivity, Spartina alterniflora (short), Distichlis spicata, Salicornia spp., Maryland-Virginia

II-B-27

Cahoon, D.R. 1975. Net productivity of emergent vegetation at Horn Point salt marsh. M.S. Thesis. University of Maryland. 94 pp.

Analyses of monthly standing crop, daily rates of production, and variations in yearly productivity for five major vegetation zones, and estimations of underground production for the Spartina patens/Distichlis spicata mixture were conducted over two consecutive growing seasons for a Chesapeake Bay brackish marsh. Regression models for plant height and dry weight biomass were generated for all seasons of the year, and covariance analysis demonstrates that the relationship between height and dry weight within each species is the same for all seasons of the year except in the species Spartina alterniflora and Phragmites australis. Positive correlation coefficients ranged from 0.2 for S. alterniflora to 0.96 for P. australis with the other species having intermediate values. Overall, production at Horn Point is lower than most other values in the literature with the 2-year average value for S. alterniflora (676 g/m^2) being one-half the average for the Atlantic coast, but with the 2-year average for S. patens (628 g/m^2) being slightly higher than that of the Atlantic coast. On a square meter basis, the primary producers rank in the following order of importance for the two-year average of standing crop: Typha angustifolia (985 g/m^2), Phragmites australis (892 g/m^2), S. alterniflora/Amaranthus cannabinus (676 g/m^2), S. patens/D. spicata (628 g/m^2) and Hibiscus moscheutos (516 g/m^2). However, the most important zones in terms of areally weighted production (in metric tons) for 1973 at Horn Point Marsh are the S. patens/D. spicata (7.61), H. moscheutos (5.07), S. alterniflora/A. cannabinus (3.22), P. australis (0.659), and T. angustifolia/H. moscheutos (0.644).

In the brackish marsh (S. patens/D. spicata), exclosure experiments demonstrated that almost 100 percent of the net primary production (NPP) passes through the detritus food chain, but in the contiguous fresh marsh (H. moscheutos) 37 percent of the NPP is utilized by the grazing food chain. Underground production for S. patens/D. spicata was determined by an experimental approach involving transplantation of underground material and a dry weight shoot-to-root ratio of 1:16 was determined over a twelve-month period. An efficiency rate for conversion of visible solar radiation to plant production in 1974 ranged from 0.11 percent for H. moscheutos in the Typha/Hibiscus zone to 1.12 percent for the T. angustifolia/H. moscheutos mixture. (A.A.)

Keywords: productivity, saltmarsh plants, biomass, food chains, Chesapeake Bay

II-B-28

Johnson, M. 1970. Preliminary report on species composition, chemical composition, biomass, and production of marsh vegetation in the upper Patuxent Estuary, Maryland. Chesapeake Biological Laboratory, Solomons, Md. Ref. No. 70-130.

In the Patuxent Estuary, extensive marshes occur over a wide range of salinities and nutrient conditions. This study was concerned with the primary production of the Patuxent marshes and the relationship of this production to the nutrient content of the water flooding the marsh. Studies showed that there were two major communities of plants in each of the two marshes chosen as examples. Maloy Marsh had one community with varying dominance, the mixed vegetation community, and one community with Typha latifolia as the dominant plant. One community in Fenno Marsh was dominated by Phragmites communis, the other by Spartina alterniflora.

By assuming that the maximum standing crop can be used to obtain a good estimate of net primary production, the following production figures were calculated. The Typha latifolia community produced 966 g dry matter $m^{-2}yr^{-1}$; the mixed vegetation community produced 1246 g dry matter $m^{-2}yr^{-1}$. The Spartina alterniflora community produced 1207 g dry matter $m^{-2}yr^{-1}$, and the Phragmites communis community 1451 g dry matter $m^{-2}yr^{-1}$. The average production of all communities is 1218 g dry matter $m^{-2}yr^{-1}$. The total production of all the Patuxent marshes is estimated at 23.3×10^6 kg dry matter yr^{-1} , of which 231×10^3 kg is nitrogen and 39×10^3 kg is phosphorus.

The quantity of nutrient-rich organic matter that could potentially be released to the river by the decomposition of the marsh plants is large. However, it is not known how much is decomposing in the marsh and how much is exported to the river. The relative contributions

of marsh production, phytoplankton production, and organic matter from upland drainage must be calculated to determine the real importance of the marsh to primary consumers in the river. (B.W.)

Keywords: saltmarsh plants, biomass, productivity, nutrients, Maryland

II-B-29

Sullivan, M.J., and F.C. Daiber. 1974. Response in production of cord grass, Spartina alterniflora, to inorganic nitrogen and phosphorus fertilizer. Chesapeake Science 15:121-123.

Fertilization of a low marsh area inhabited by the cord grass Spartina alterniflora with inorganic nitrogen and phosphorus compounds was conducted on a monthly basis during the 1972 growing season. Yield of the cord grass, as measured by an increase in fresh weight after its harvest, was significantly higher in the nitrogen fertilized area when compared to the phosphorus fertilized site and a control area. No effect of phosphorus could be demonstrated. It was concluded that nitrogen supplies are limiting production of dwarf form S. alterniflora in the salt marsh under study and further suggested that introduction of additional sources of inorganic nitrogen into a marsh deficient in nitrogen would tend to increase its productivity.

Annual Spartina alterniflora above-ground production (g fresh wt/m⁻²) was determined:

Control Dwarf	1544
N added	1808
P added	4208

(A.A.)

Keywords: Spartina, cordgrass, mineral nutrients, productivity, Delaware

II-B-30

Morgan, M.H. 1961. Annual angiosperm production on a salt marsh. M.S. Thesis. University of Delaware. 34 pp.

Quantitative measurements were made in selected areas on the Canary Creek Salt Marsh to determine the quantity of angiosperm plant material produced during the 1960 growing season. Production was measured by the clip quadrat method.

Preliminary analysis demonstrated that 24 half-square-meter samples were adequate for each sampling date. Net production is represented as the sum of the amount of living material present at the end of

the growing season and the increase in dead material during the growing season. The marsh was found to produce 445 grams at a rate of 5.32 g dry wt/m²/day. Production was found to vary over the surface of the marsh and was associated with drainage conditions. (Author's summary)

Keywords: salt marshes, productivity, marsh plants, plant litter, Delaware

II-B-31

Good, R.E. 1965. Salt marsh vegetation, Cape May, New Jersey. Bulletin of the New Jersey Academy of Science 10(1):1-11.

A study was made of Goshen Creek salt marsh in Cape May County, New Jersey, during the summers of 1963 and 1964. The objectives of the study were to investigate the vegetational and environmental patterns and determine relationships among them; to obtain an estimate of productivity for the salt marsh; and to evaluate the methods used. Forty-nine stands were sampled by the point-centered quarter method, which was modified to obtain an estimate of standing crops by a collection of the plants measured at the points.

The stands were compared by coefficient of community techniques and then arranged along an axis by means of ordination techniques. Determinations were made for the environmental factors of salinity and depth of flooding. The greater part of the area was dominated by Spartina alterniflora. Spartina patens and Distichlis spicata were the next most important species.

The lack of a continual change in composition of the stands along the ordination axis suggests that distinct communities exist of which Spartina alterniflora and S. patens make up almost pure stands. They clearly stand out in the ordination diagram and can be considered as distinctive associations. Examination of other stands of the ordination also suggested that there was little validity in applying the continuum concept to salt-marsh vegetation.

The point-centered quarter method provides accurate information for density and standing crop only for species that are randomly dispersed (Spartina alterniflora). Results indicated that certain stands dominated by Spartina alterniflora gave the highest estimates of standing crop (maximum of 532 grams/m² and an average of 300 grams/m²). These values were similar to values for a Delaware salt marsh, but lower than values for Georgia salt marshes.

The results further indicated that high estimates of standing crop (which occurred primarily along the creeks) were associated with frequent floodings and moderate salinities, while low estimates of

standing crop (which occurred in pannes) were associated with infrequent floodings and wide ranges of salinities. Both sites are dominated by Spartina alterniflora, with the tall form occurring along creeks and the stunted form occurring in pannes. (A.A.)

Keywords: salt marsh, marsh plants, Spartina, productivity, New Jersey

II-B-32

Nadeau, R.J. 1972. Primary production and export of plant materials in the salt marsh ecosystem. Ph.D. Thesis. University of New Jersey. 175 pp. (Diss. Abstr. 33:1504-B)

Metabolism of mudflat algal, marsh surface algal, and drainage ditch phytoplankton communities for a New Jersey salt marsh ecosystem was investigated for two years (November 1968-August 1970). Standing crop measurements of the salt marsh grass community were determined midway and at the end of each growing season.

Mudflat algal productivity rates averaged $7.5 \text{ mg C/m}^2/\text{hr}$ during 1969 (July-November) and $10 \text{ mg C/m}^2/\text{hr}$ for 1970 (April-August). Marsh surface algal production rate averaged $3.0 \text{ mg C/m}^2/\text{hr}$ during 1969 (July-November) and $5.0 \text{ mg C/m}^2/\text{hr}$ for 1970 (April-August). Hourly respiration rates for both communities were less than gross productivity rates for most of the season. Total respiration for a 24-hour day was greater than gross productivity, resulting in negative net productivity for both communities during the summer and autumn.

Gross production rates for the drainage ditch phytoplankton community averaged $268 \text{ mg C/m}^2/\text{day}$ from November 1968 through October 1969 and $360 \text{ mg C/m}^2/\text{day}$ from November 1969 through August 1970. In the winter, respiration and production were less than in the summer.

Spartina alterniflora, growing along the ditch borders, had the largest end-of-year standing crop (520 g/m^2) for both seasons. The high marsh salt meadow grass, S. patens, was nearly as productive, averaging 409 g/m^2 for both seasons. Short form S. alterniflora was not so productive (385 g/m^2).

Litter accumulation from previous growth averaged $260 \text{ g (dry wt)/m}^2$ in the high marsh area, whereas in the border zone the litter was removed by tidal action and accumulation was negligible. The amount present in the high marsh decreased as the growing season progressed, signifying (1) incorporation of litter into the soil-building process and (2) herbivore consumption.

Seven tidal cycles were monitored during the study. A seine was used to collect floating debris, mainly S. alterniflora stalks and leaves, which were removed from the ecosystem during each ebb tide.

During the growing season, the floating debris was composed of fresh S. alterniflora stalks and leaves, while for the remainder of the year it consisted of border zone litter. No net contribution of suspended particulate material was observed during the tidal cycles monitored. Decomposition of floating debris into detrital size material occurs more within the aquatic community than on the salt marsh proper and is incorporated into the food web of the estuarine communities. (A.A.)

Keywords: primary productivity, algae, phytoplankton, Spartina, detritus, New Jersey

II-B-33

Potera, G.T., and E.E. MacNamara. 1972. Sparta (sic) alterniflora (tall) productivity in a polluted New Jersey estuary. Bulletin of the New Jersey Academy of Science 17(1):13-14.

Net primary productivity for the cordgrass S. alterniflora (tall) was measured at several harvest sites in a polluted northern New Jersey estuary. Average productivity for the New Jersey sites was more than 40 percent greater than cordgrass productivity reported for Hempstead, Long Island. The significant increase in productivity was attributed to a slightly longer growing season. (J.B.)

Keywords: primary productivity, Spartina alterniflora (tall), cordgrass, New Jersey

II-B-34

Squiers, E.R., and R.E. Good. 1974. Seasonal changes in the productivity, caloric content, and chemical composition of a population of salt-marsh cord-grass (Spartina alterniflora). Chesapeake Science 15:63-71.

During the 1972 growing season, the productivity of short form and tall form of Spartina alterniflora was studied by the harvest method in the vicinity of the Rutgers Marine Sciences Center on Great Bay near Tuckerton, New Jersey. The aboveground biomass of living and dead grass was determined, and subsamples were analyzed for caloric equivalents, ash, nitrogen, crude protein, crude fiber, ether extract, and nitrogen-free extract.

S. alterniflora had peak standing crops of $1,592 \text{ g/m}^2$ for tall form and 592 g/m^2 for short form. Standing crops of crude fiber, ether extract, nitrogen-free extract, and caloric values are a function of dry matter production, while nitrogen components seem to be influenced by some other factor. Seventy percent of the crude protein was present in early summer at a time when dry weight was less than 5 percent of its maximum value. The data indicate that the amount of nitrogen that the plant accumulates

in its aboveground parts early in the growing season is directly related to the peak of dry matter standing crop. The early spring accumulation of nitrogen may act to offset shortages at the peak of the growing season. The chemical composition of litter and soil samples suggests that biological breakdown of plant material occurs at the soil surface. (A.A.)

Keywords: Spartina alterniflora, productivity, salt marshes, cord-grass, New Jersey

II-B-35

Udell, H.F., J. Zarudsky, T.E. Doheny, and P.R. Burkholder. 1968. Productivity and nutrient values of plants growing in the salt marshes of the Town of Hempstead, Long Island. Bulletin of the Torrey Botanical Club 96:42-51.

The abundance and chemical composition of marsh grasses, sea lettuce, and phytoplankton were determined in the Hempstead Bay estuary of the Town of Hempstead, Long Island, New York, in 1967. The marshland comprises about 6,700 acres and the aquatic environment some 11,500 acres. Species of marsh grasses belonging in the genera Spartina and Distichlis produce an estimated 17,113 tons of dry matter per year in the Hempstead estuary, while the aquatic sea lettuce and phytoplankton produce 21,955 tons. The primary producers of organic matter in the Hempstead estuary are shown to form valuable quantities of protein, fat, carbohydrates and vitamins. Protein content of marsh grasses ranged from 9.6 percent to 14.9 percent of dry weight. Zostera yielded 14.6 percent and Ulva 20.8 percent protein in dry matter. In the species of Ulva, Zostera, Spartina and Distichlis, ash content varied from 5.5 percent to 58.2 percent, fat ranged from 0.5 percent to 2.9 percent and carbohydrate yielded from 18.2 percent to 63.9 percent. Four B vitamins were present in adequate amounts to satisfy the requirements of grazing animals and microorganisms. Vitamin B₁₂ occurred in relatively small amounts (0.008 to 0.022 microgm/gm) in the flowering plants, but Ulva yielded 0.26 microgm of B₁₂ per gram of dry matter. These nutrients and essential growth factors are available for direct assimilation by herbivores, and through microbial transformation to detritus they also supply indirectly valuable stores of particulate matter for filter feeders and other marine life. (A.A.)

Keywords: primary productivity, nutrient values, salt marshes, marsh grasses, Long Island

II-B-36

Harper, R.M. 1918. Some dynamic studies of Long Island vegetation. Plant World 21:38-46.

This was one of the first studies to be made of the productivity of natural herbaceous vegetation. During 1916, the author studied seven separate areas of herbaceous vegetation in the western part of Long Island. Four of these were marsh areas: 1) a brackish marsh with a pure stand of Spartina patens; 2) a nearby marsh dominated by Typha latifolia; 3) the same marsh, but that portion dominated by Phragmites communis; and 4) a fresh marsh dominated by Typha augustifolia. One square yard was the unit of area selected for each sample. The productivity values, expressed in pounds per acre, were as follows:

Type	Fresh	Dry	Ash
1. <u>Spartina patens</u>	16,940	8,848	279
2. <u>Typha latifolia</u>	31,460	12,100	296
3. <u>Phragmites communis</u>	48,400	24,000	1,585
4. <u>Typha augustifolia</u>	53,240	15,443	843

(J.B.)

Keywords: productivity, aquatic plants, freshwater marsh, saltwater marsh, Long Island

II-B-37

Nixon, S.W., and C.A. Oviatt. 1973. Ecology of a New England salt marsh. Ecological Monographs 43:463-498.

Measurements of the abundance of major populations, their metabolism, and the seasonal patterns of total system metabolism throughout a year were used to develop energy flow diagrams for a New England salt-marsh embayment. The annual ecological energy budget for the embayment indicates that consumption exceeds production, so that the system must depend on inputs of organic detritus from marsh grasses. Gross production ranged from almost zero in winter to about $5 \text{ g O}_2 \text{ m}^{-2} \text{ day}^{-1}$ in summer. Respiration values were similar, but slightly higher, with the maximum difference observed in fall. Populations of shrimp and fish were largest in fall, with a much smaller peak in spring. Few animals were present in the embayment from May to July, but fall populations of shrimp ranged from 250 to 800 m^{-2} and fish averaged over 10 m^{-2} . Birds were most abundant in winter and spring. In spite of high numbers, no evidence was found that the marsh embayment exported large amounts of shrimp or fish to the estuary. Production of aboveground emergent grasses on the marsh equaled 840 g m^{-2} for tall Spartina alterniflora, 432 g m^{-2} for short S. alterniflora, and 430 g m^{-2} for S. patens.

These values are similar to those for New York marshes, but substantially lower than the southern marsh types. The efficiency of production of marsh grasses in the New England marsh was lower than reported for southern areas.

A simulation model based on the laboratory and field metabolism and biomass measurements of parts of the embayment system was developed to predict diurnal patterns of dissolved oxygen in the marsh. The model was verified with field measurements of diurnal oxygen curves. The model indicated the importance of the timing of high tides in determining oxygen levels and was used to explore simulated additions of sewage BOD and increases in temperature.

Energy flow diagrams for the marsh system on representative days in summer and winter are presented. Effort is directed toward expanding details of the energy flow in the marsh creeks and embayments that are coupled with the tall stands of grass and serve as tidal pathways linking the emergent marsh with larger estuaries and offshore waters. Emphasis is placed on the great importance of detrital food chains and large sedimentary organic storage in the embayment. The diagrams also indicate that large standing crops of plants and animals may be supported in the marsh-embayment complex, and that high levels of primary production occur over short periods from submerged vascular plants, attached algae, and phytoplankton in the embayment. However, the marsh embayment appears to be a consumer system that depends on the import of organic matter fixed on the emergent marsh by grasses and sediment algae.

A table is given providing the annual energy budget for a marsh embayment. The value used for total organic input to the embayment is largely a function of the estimate of detritus entering from the emergent marsh.

The results of this study indicate that even in the less extensive marshes of New England, the development of large populations of fish and shrimp in the marsh area can be documented, and that the maintenance of the system necessary for the culture of these large populations depends on inputs of organic matter from the productive meadows of Spartina. (A.A. and H.D.)

Keywords: salt marshes, energy flow, primary productivity, New England, Rhode Island

II-B-38

Nixon, S.W., and C.A. Oviatt. 1973. Analysis of local variation in the standing crop of Spartina alterniflora. Botanica Marina 16:103-109.

Measurements of standing crop biomass and height of the tall form of Spartina alterniflora on twelve Rhode Island salt marshes suggest that the nutrients in municipal sewage inputs may increase growth of the grass. Spartina biomass in the Providence River and upper Narragansett Bay was 39 percent greater than in the lower Bay and 107 percent greater than in Block Island Sound. Height of the plants increased 5 percent and 67 percent over those in the lower bay and sound, respectively. Even with enhanced growth from eutrophication, calculations show that treatment of marsh areas with sewage effluents is not a realistic hope for the recycling of wastes from coastal cities, or for providing low cost tertiary treatment.

The mean dry weight at the end of the growing season was $840 \pm 321 \text{ g/m}^2$ for all marshes, with a range from $433 \pm 80 \text{ g/m}^2$ to $1380 \pm 220 \text{ g/m}^2$. Grass height averaged $112 \pm 28 \text{ cm}$ on all sites, with a range from $50 \pm 12 \text{ cm}$ to $142 \pm 16 \text{ cm}$. Multiple regression analysis indicated that concentrations of ammonia, sediment phosphorus, and sediment nitrogen could account for 77 percent of the between site variation in Spartina standing crop. Grass height was correlated with sediment iron in a manner suggesting this element as a possible limiting factor.

Half of the twelve marshes were significantly different from all other sites in terms of grass height, demonstrating the importance of having samples from a variety of marshes in each area when analyses of large climatic gradients on production are attempted. (A.A.)

Keywords: Spartina, biomass, salt marshes, mineral nutrition, productivity, Rhode Island

II-B-39

Valiela, I., J.M. Teal, and W.J. Sass. 1975. Production and dynamics of salt marsh vegetation and the effects of experimental treatment with sewage sludge. Journal of Applied Ecology 12:973-981.

Fertilization with a 10-6-4 sewage sludge fertilizer increased the total peak standing crops of salt marsh vegetation, in spite of the presence of considerable amounts of heavy metals and chlorinated hydrocarbons in the sludge. Increases in standing crop were detected in the second year of treatment and remained for three years of treatment. The increases in biomass are believed to be due to the addition of nitrogen.

Spartina alterniflora, which was the dominant species in low marsh areas, progressively excluded Salicornia spp. from the fertilized plots after an initial increase of Salicornia. In high marsh

areas, fertilization initially increased the standing crop of Distichlis spicata but this was later replaced by Spartina patens. S. alterniflora did not respond to fertilization in the high marsh.

The amount of dead matter in both high and low marsh was highest in the fall, after death of the sward, and decreased slowly to a low point in midsummer. The amount of dead matter was never equal to peak live biomass, implying decomposition or tidal export. The production achieved by the most heavily fertilized plots were among the highest recorded for marsh plants, except that of tall form S. alterniflora in exceptionally favorable sites.

Treatments converted low marsh vegetation, consisting mainly of dwarf form S. alterniflora, into a sward approaching the biomass and morphology of tall form. The authors conclude that the so-called "forms" are a response to nitrogen supply.

The effect of sludge fertilizer on the net annual production (gm^{-2}) and peak aboveground biomass (gm^{-2}) on low marsh and high marsh vegetation for each of three years was determined:

Treatment	Year	Low marsh		High marsh	
		Net Production	Peak Biomass	Net Production	Peak Biomass
High Dosage	1971	1530	1550	1230	1350
	1972	1130	1130	1080	880
	1973	1310	870	1460	780
	Mean	1320	1180	1260	1000
Low dosage	1971	780	650	1410	880
	1972	870	870	960	1000
	1973	910	710	1770	1020
	Mean	860	740	1380	970
Control	1971	360	280	620	440
	1972	440	250	540	350
	1973	720	420	730	540
	Mean	510	320	630	440

(Author's summary)

Keywords: productivity, saltmarsh plants, biomass, nutrients, Spartina, Distichlis, high salt marsh, Massachusetts

II-B-40

Valiela, I., J.M. Teal, and N.Y. Persson. 1976. Production and dynamics of experimentally enriched salt marsh vegetation: belowground biomass. *Limnology and Oceanography* 21:245-252.

Root growth increased during the early growing season in Spartina alterniflora salt marsh plots. While fertilization with nitrogenous fertilizer did not affect initial growth, a marked decrease in root biomass followed the spring peak, particularly where nutrient doses were highest. A sharp reduction in roots occurred in enriched areas covered by S. patens, although, as with S. alterniflora, aboveground biomass increased. Roots disappeared during autumn leaving rhizomes as the only part of the plants to overwinter. The maximum standing crop for roots was 0-2 cm deep; for rhizomes 2-5 cm. Net annual underground production was calculated from annual increments in dead matter belowground. Total production, underground and aboveground, exceeds that of any other marine vegetation, ranging from 3,900 to 6,600 g m⁻²yr⁻¹ in S. alterniflora areas and 3,200 to 6,200 g m⁻²yr⁻¹ in S. patens areas. Fertilization increased production, particularly aboveground where dead plant parts are subject to export. (A.A.)

Keywords: productivity, saltmarsh plants, biomass, Spartina, nutrients, U.S. Atlantic coast, Massachusetts

C. Algae and Phytoplankton Productivity Studies

II-C-1

Pomeroy, L.R. 1959. Productivity of algae in salt marshes. Pages 88-96 in *Proceedings of the salt marsh conference, Sapelo Island, Georgia*. University of Georgia, Athens.

The surface layers of the sediments in salt marshes contain a diversified population of algae. Pennate diatoms of many genera and species are abundant. Dinoflagellates, green, and blue-green algae are also present. Although the algal population of the marshes is inconspicuous, and the standing crop is small, the rate of growth of the population is rapid, and growth continues throughout the year. The amount of energy transformed by algal photosynthesis is a significant contribution to the total primary production of the salt-marsh ecosystem.

Photosynthesis of the marsh algae was measured under bell jars filled with filtered, boiled estuarine water (by change in oxygen content of the water) and made at various elevations on the side of a natural levee beside the Duplin River, a tidal drainage creek. These were taken to represent production in other areas of the marsh having similar elevation, density of Spartina, and temperature conditions.

Underwater production reaches a peak rate of about 200 milligrams of carbon fixed per square meter of marsh surface per hour (gross algal production: the total primary product of photosynthesis) during August and drops to about 50 milligrams in winter. For periods when the marsh is exposed to air, a peak rate of about 150 milligrams is reached in January. Production drops nearly to zero in March, and gradually rises again through the rest of the year.

Daily rates of production were estimated from the short-term (1 hour) production measurements by correcting for day length and amount of time various parts of the marsh are exposed to air and flooded with water during a tidal cycle. From the daily production estimates, an estimate of annual production was made which was weighted according to the amount of marsh in the study area having certain elevation and Spartina density. The mean annual production for Georgia salt marshes was estimated to be 200 grams of carbon per square meter (gross algal production).

Net algal production was estimated at probably more than 90 percent of gross production. There is no evidence that the supply of carbon dioxide is limiting to underwater photosynthesis, but it may sometimes be limiting to photosynthesis in air. The pH of the surface of the marsh sediments rises from an early morning low of about 7.5 to 9 or even 10 during the day. When only the algal production is considered and the Spartina is ignored, the primary productivity of the salt marshes can be considered comparable to that of many other aquatic ecosystems, such as lakes and oceans, but lower than many terrestrial and some flowing aquatic ecosystems. Considerable discussion follows presentation of the paper. (G.S.)

Keywords: primary productivity, algae, Spartina, Georgia

II-C-2

Pomeroy, L.R. 1959. Algal productivity in salt marshes of Georgia. *Limnology and Oceanography* 4:386-397.

Salt marshes support several populations of primary producers: higher plants, algae on and in the sediments, and phytoplankton in the estuarine water. Much work has been done on phytoplankton production, and the production of Spartina alterniflora, the dominant spermatophyte of Atlantic coast marshes, has been investigated; but the possible role of the benthic microflora as producers has been largely overlooked.

This study is concerned with the productivity of the microscopic algae of intertidal salt marshes and with the environmental conditions that influence it. Most of the measurements of production and associated factors were made in the marshes of the Duplin River, a tidal creek adjacent to Sapelo Island, Georgia.

Gross primary production of algae in the intertidal marshes on the coast of Georgia was measured at various seasons. Measurements were also made of light, temperature, pH, depth of flooding at high tide, and sedimentary chlorophyll. Migration of the algae in the sediments was observed along creek borders.

Production during low tide is $150 \text{ mg C/m}^2/\text{hr}$ in winter and $20\text{--}30 \text{ mg C/m}^2/\text{hr}$ in summer. Production under water during high tide is $200 \text{ mg C/m}^2/\text{hr}$ in August and drops to 50 mg in winter. A relation between the changes in production and the regime of light, temperature, and tides is postulated. Changes in production during high and low tide alternate so as to result in a nearly constant daily production throughout the year. The annual gross algal production is estimated to be 200 g C/m^2 . Net production is not less than 90 percent of gross production. Photosynthetic efficiency varied from 3 percent to less than 0.1 percent.

Because marshes make up about 75 percent of the area of the estuaries of the coast of Georgia, the production of marsh plants is important in its contribution to the energy flow of estuarine populations. The rate of algal production in Georgia salt marshes was found in this study to be similar to the production of phytoplankton in many aquatic ecosystems. When the total production of the marshes is estimated, including Spartina and phytoplankton as well as the algae of sediments, it will probably be comparable to the most productive aquatic and terrestrial ecosystems. Certainly the production of algae in salt marshes is a significant contribution to the energy flow of the ecosystem of marshy estuaries. (J.B.)

Keywords: primary productivity, algae, Spartina, Georgia

II-C-3

Gallagher, J.L., and F.C. Daiber. 1974. Primary production of edaphic algal communities in a Delaware salt marsh. *Limnology and Oceanography* 19:390-393.

Gross primary production of edaphic algae was estimated for five areas in a high salinity tidal marsh near Lewes, Delaware. Salt pan and bare bank (free of angiosperms) algal production did not vary significantly from one part of the year to another. Algal productivity in the tall Spartina alterniflora and Distichlis spicata areas was greatest from mid-January to mid-May. In the short S. alterniflora area, algal productivity did not decrease in the warmest part of the year as it did in the two other grass areas. Annual cycles of light, temperature, and salinity were measured. Gross algal production was about one-third of the angiosperm net production. Since much of the algal production occurs when angiosperms are dormant, it complements the pattern of angiosperm energy fixation. (A.A.-reduced)

Keywords: primary productivity, algae, Spartina alterniflora (tall and short), Delaware

II-C-4

Gallagher, J.L. 1971. Algal productivity and some aspects of the ecological physiology of the edaphic communities of Canary Creek tidal marsh. Ph.D. Thesis. University of Delaware. 125 pp. (Diss. Abstr. 32:6353-B).

Gross algal primary productivity and edaphic community respiration estimates were made for five areas of Canary Creek tidal marsh near Lewes, Delaware. Oxygen changes in water overlying cores of the marsh incubated in the laboratory were used as the indication of metabolic activity. Environmental factors of light, temperature, salinity, pH, nutrient content of surface water and the nitrogen and phosphorus content of the grass were measured.

Bare bank and panne algal productivity did not vary significantly from one part of the year to another. Algal productivity in the tall Spartina alterniflora and Distichlis spicata areas was greatest in the period from mid-January to mid-May. In the dwarf form Spartina alterniflora area algal productivity did not drop in the warmest part of the year as it did in the two other grassy areas. Algal productivity in the several areas tested was not inhibited by illuminances of 103 kilolux from quartz-bromide lamps. Saturation occurred at approximately one-half of full light in most cases. An apparently diel, endogenous productivity rhythm was observed in the tall and dwarf Spartina areas.

It was estimated that the algae produce 160 g of ash free dry matter per m²/year. About 0.1 percent of the photosynthetically active energy available above the angiosperms was stored by the algae. Edaphic community respiration requires nearly three times the algal oxygen output. Respiration was approximately twice as high during the mid-May through mid-September period as in either of the other 2 four-month periods of the year. No endogenous respiratory rhythm with appreciable amplitude was detected. Exogenous respiratory rhythms were present as the result of temperature changes during the day. Q₁₀ values ranged from 1.1 to 2.2.

Although the gross algal production is only about one-third the net angiosperm production, the algal production may be more important than its annual production indicates, since much of it occurs at a time when the grasses are dormant. (A.A.)

Keywords: algae, primary productivity, tidal marsh, Spartina, Distichlis, Delaware

II-C-5

Stowe, W.C. 1972. Community structure and production of the epiphytic algae in the Barataria Bay area of Louisiana. M.S. Thesis. Louisiana State University. 84 pp.

Annual primary production and community respiration were determined for the epiphytic algae associated with Spartina alterniflora Loisel., in the southwestern Barataria Bay area of Louisiana. Changes in production and respiration were related to changes in the algal standing crop.

The epiphytes were divided into two communities: (1) those associated with the Spartina located at the water's edge (the grass-water interface) and (2) those associated with the Spartina located 1.5 meters inland from the water's edge.

Structurally, the presence of macroscopic algae at the water's edge and their absence inland was one of the most noticeable differences between the two locations. At the microscopic level distinct diatom communities were observed at the two locations.

The two locations were very different with regard to productivity. The water's edge community exported 16.06 g C/m^2 annually, whereas the inland community required the import of 63.44 g C/m^2 annually for maintenance. (A.A.)

Keywords: community structure, productivity, algae, Spartina, Louisiana

II-C-6

Gallagher, J.L. 1973. The significance of the surface film in plankton primary production in a salt marsh. *Journal of Phycology* 9(Suppl.):8.

The significance of the surface film on the water overlying a Georgia salt marsh was compared with that of the water column below with respect to numbers of algal cells, chlorophyll content and primary production. Surface film was collected by its adhesion to glass for the cell counts and chlorophyll determinations (fluorometric) and on Nitex cloth for productivity studies. Cell counts and chlorophyll were highest in the surface film on the rising tide with a sharp increase occurring just before high tide. At maximum development the surface film was at least several orders of magnitude richer in chlorophyll than the water beneath on an equal volume basis. Area comparisons were also made assuming various water depths. As the tide ebbed the film adhered to the plant and soil surfaces. During maximum currents there was little difference between the surface film and the water column in the larger creeks. Primary production studies indicated the cells (primarily pennate diatoms) in the surface film were not senescent and were photosynthetically active. (A.A.)

Keywords: primary production, plankton, salt marshes, Georgia

II-C-7

Ragotzkie, R.A., and L.R. Pomeroy. 1957. Life history of a dinoflagellate bloom. *Limnology and Oceanography* 2:62-69.

In late February and early March 1955, a small, dense concentration of a dinoflagellate of the genus Gymnodinium was observed in the extreme upper end of the Duplin River at Sapelo Island, Georgia. This river is estuarine in character and receives practically no freshwater runoff from land.

The authors describe the bloom in terms of its distribution, growth rate, production, and rate of diffusion. Production measurements on a second bloom of the same organism are also cited. In the center of the first bloom, cell concentrations ranged from 1 to 18 million cells per liter. Net production ranged from 2.18 to 13.7 mg C/liter/day. Coefficients of horizontal eddy diffusion, as calculated from the observed dinoflagellate distributions, were low, ranging from near zero to 350 g/cm/sec. (A.A. and introduction)

Keywords: dinoflagellate, estuary, Georgia

II-C-8

Ragotzkie, R.A. 1959. Plankton productivity in estuarine waters of Georgia. *Publications of the Institute of Marine Science, University of Texas* 6:146-158.

Primary production of the plankton community in the estuarine waters near Sapelo Island, Georgia, was estimated by oxygen evolution in light and dark bottles at several locations. Data on temperature, light, and chlorophyll a were obtained for most of the experiments. The average gross production by plankton was +0.68 gm C/m²/day, and net planktonic community production averaged -0.038 gm C/m²/day. The plankton community tended to be heterotrophic in the summer and autotrophic in the winter. The primary factor limiting production was light. Analysis of compensation depths and extinction coefficients shows that, for the mean depth of these waters and under the observed conditions of light and vertical mixing, net production by the plankton community must be near zero regardless of the standing crop. The salt marsh is postulated as an outside source of organic matter of the system. (A.A.)

Keywords: primary productivity, plankton, estuary, Georgia

II-C-9

Schelske, C.L. 1962. Phytoplankton productivity in a Georgia estuary. Page 337 in D.S. Gorsline, ed., Proceedings of the first national coastal and shallow water research conference, October 1961. National Science Foundation and Office of Naval Research, Tallahassee. (Abstr.)

Both the factors controlling phytoplankton production and the magnitude of phytoplankton production are considered for a Georgia estuary. Nutrients are abundant in these estuarine waters and are not important limiting factors. High turbidity limits light penetration, which minimizes photosynthetic activity at depths below two meters.

Phytoplankton production is measured at selected depths using both the carbon-14 method and the light- and dark-bottle oxygen method. These measurements are for periods of less than six hours. The intensity (rate per unit volume) of production is high in the upper two meters where there is sufficient light for high rate of photosynthesis. (A.A.)

Keywords: phytoplankton, primary productivity, estuary, Georgia

II-C-10

Pomeroy, L.R. 1960. Primary productivity of Boca Ciega Bay, Florida. Bulletin of Marine Science of the Gulf and Caribbean 10:1-10.

The relative importance of turtle grass, phytoplankton, and the benthic microflora as primary producers was determined in Boca Ciega Bay, Florida. The relative importance of phytoplankton, marine spermatophytes, and the benthic microflora as primary producers varies with the depth of the water. In water less than two meters in depth, which makes up 75 percent of the bay, the three are about equally important. In deeper water only phytoplankton is significant. The methods used and the estimation of community production are discussed. (H.D.)

Keywords: primary productivity, marsh grasses, phytoplankton, algae, Florida

II-C-11

Moll, R.A. 1974. The phytoplankton community of a temperate zone salt marsh. Ph.D. Thesis. State University of New York at Stony Brook. 134 pp. (Diss. Abstr. 35:2536-B)

A study of the phytoplankton community in Flax Pond, a Long Island salt marsh, from June 1972 to October 1973 revealed relatively little net primary production. Thirteen variables were sampled at three locations in the marsh every other hour throughout the photoperiod

once per week. Some of the more important variables sampled included chlorophyll, nitrogen, extinction coefficient, and primary production. These data were used in a multiple linear-regression equation to predict net production in Flax Pond. This equation predicted that in the marsh 11.8 grams of carbon were fixed as net production per square meter per year, compared to 593 grams per square meter per year potentially fixed in Long Island Sound. Samples collected by Brookhaven National Laboratory in a concurrent study showed a large net flux of phytoplankton from the Sound. Production within the marsh, as well as transport of phytoplankton into Flax Pond, provided over nine kilograms of carbon per square meter of marsh per year available to higher trophic levels. Although chlorophyll measurements were significantly correlated with productivity and total numbers of phytoplankton cells, previous investigations suggested that these correlations should have been higher. The relationship of pH and carbon dioxide to net production was confounded due to high levels of respiration in the marsh and the mixing effect of water brought in with the tides. A multivariate analysis of variance showed that considerable variation is introduced into the data by the effect of time of year. Lesser, but significant, amounts of variation were introduced from the effect of time of day within the photoperiod at which samples were taken and location of sampling within the marsh. (A.A.)

Keywords: primary productivity, phytoplankton, salt marsh, Long Island

II-C-12

Thayer, G.W. 1969. Phytoplankton production and factors influencing production in the shallow estuaries near Beaufort, North Carolina. Ph.D. Thesis. North Carolina State University at Raleigh. 179 pp. (Diss. Abstr. 31:7243-B)

Three aspects of the ecology of phytoplankton in a system of shallow estuaries near Beaufort, North Carolina, were examined in a yearlong study: 1) the seasonal distribution of phytoplankton production and inorganic nutrients; 2) identification of nutrients limiting for phytoplankton; and 3) the turnover of phosphorus. Photosynthesis was measured under laboratory conditions using the carbon-14 method. Limiting nutrients were identified with nutrient enrichment techniques. Phosphorous turnover was estimated with radioactive phosphorus.

Photosynthesis and chlorophyll *a* had pronounced and similar seasonal distributions that followed the cycle in water temperature. Production was minimum at most stations during December and maximum during June and July. Annual phytoplankton production ranged from 16 g C/m² in a small embayment, having an average depth of 0.4 m, to 153 g C/m² at the seaward end of the Newport River estuary. Annual production for the system averaged 66.6 g C/m². Phosphorous concentrations were generally low throughout the year. Maximum concentrations of phosphorus occurred

during June and July. Maximum nitrate concentrations occurred during late May. The pulse in production during summer was ascribed to the accumulation of available nitrogen prior to, and increases in dissolved inorganic phosphorus during, the pulse. A general dearth of nutrients was probably the prime factor limiting production.

Nutrient enrichment experiments indicated that nitrate was more limiting than phosphate. The addition of organic compounds low in nitrogen and phosphorus depressed photosynthesis. This suggested that bacterial immobilization of nitrogen and phosphorus during decomposition of organic matter that may be added to the system may account for the paucity of nutrients.

Much of the phosphorus in the system was in an organic form as particulate phosphorus and dissolved organic phosphorous. Phosphorous turnover was more rapid in the estuarine areas than in the adjoining ocean. Phosphorous turnover appeared rapid enough to supply sufficient dissolved inorganic phosphorus for phytoplankton growth. (A.A.)

Keywords: phytoplankton, primary production, estuaries, North Carolina

II-C-13

Odum, H.T., and C.M. Hoskins. 1958. Comparative studies on the metabolism of marine waters. Publications of the Institute of Marine Science, University of Texas 5:16-46.

Metabolic methods were used for rapid study of whole water areas. Measurements of metabolic rates in contrasting waters indicated qualitative contrasts and a wide range of values in quantitative data. Such data can provide an understanding of shallow marine bay systems anywhere and a basis for resolving conflicts.

The diurnal curve method for measuring metabolism was widely applied in the study in coastal waters with a number of tests of the methods. Rates of gross community photosynthesis (primary production) and total community respiration were determined with diurnal curve methods, dark bottle methods, mud bottle methods, and bell jar methods in marine waters of Texas, North Carolina, and British West Indies. Metabolic rates ranged from 1 to 24 gm/m²/day oxygen. Depth of the environments ranged from a few centimeters of water over blue-green algal mats to 15 m of water on the Gulf of Mexico shelf. Replications of the diurnal curve method at three similar stations were within 20 percent of the mean. Two contrasting stations were within 35 percent of the mean. Difficulties in estimating trajectory, depth, and daytime respiration were principal sources of error. Diurnal curves in open shelf waters were measurable where large numbers of duplicate Winkler analyses were made. Shapes and variations in diurnal curves were presented including inverted curves,

curves with changing diffusion constants, curves with more morning production, curves with more afternoon production, curves indicating cloud effects and curves with midday depression.

Production per area is greatest in very shallow clear bays and least in turbid deeper bays where the turbidity is due to inorganic matter. Bays with bottom plants maintain relatively stable metabolism, whereas plankton-dominated bays fluctuate more widely. Diurnal curve measurements generally exceed bottle measurements especially in shallow bays in benthic plant communities like Redfish Bay, Port Aransas, where diurnal curve metabolism is 100 times bottle metabolism. Bottle and free water methods may be similar in plankton blooms but ordinarily bottle methods in shallow marine waters do not provide community metabolism figures. Bottle methods were used in this study to estimate plankton activity.

The sum of metabolic rates from bottle measurements and bell jar measurements was less than values from diurnal curve methods. Rate data from enclosures containing benthos are believed to be low. Photosynthesis may exceed respiration on single days in all bays, but in bays with little river inflow, respiration is about equal to photosynthesis within accuracy of methods. With river inflow, respiration may greatly exceed photosynthesis, indicating support of the community from imported organic matter. The curve of percent saturation indicates dominance of heterotrophic energy support when values remain undersaturated through the day. In the upper Laguna Madre and Redfish Bay, production is maximal in the spring-summer season and minimal in the winter season as roughly correlated with light intensities and the presence of migratory faunas.

Diffusion constants calculated from diurnal curve analysis ranged 0.5 to 3.8 gm oxygen/m²/hr. at 0 percent saturation. These constants were correlated with wind, current, and wave action. The diffusion constant, as measured with the diurnal curve method, may be used to compute the steady state pollution load necessary to maintain oxygen above anaerobic levels. Total respiration (natural plus that in pollution load) must be maintained less than $R = 24 KS + P$ (gm/m²/day). The efficiency of photosynthesis in natural community conditions was found to decrease with light intensity during the middle of the day, although the total production generally increases with light intensity. A light saturation point was rarely found for community photosynthesis although in individual plants of the community, light may exceed optimum intensities for these cells. Detailed instructions are given for routine bottle and diurnal curve work in shallow marine waters. (G.S. and author's summary)

Keywords: metabolism, estuarine systems, primary production, Texas, North Carolina

II-C-14

Anderson, G.C. 1964. The seasonal and geographic distribution of primary productivity off the Washington and Oregon coasts. *Limnology and Oceanography* 9:284-302.

The distribution of chlorophyll a and phytoplankton productivity off the Washington and Oregon coasts has been observed during 14 cruises of the RV Brown Bear from January 1961 to June 1962.

Surface waters in the area covered by the Columbia River effluent generally contained more phytoplankton and had a higher rate of photosynthesis than ambient waters. The densest and most variable populations were found during summer in coastal upwelling areas and directly off the river mouth. Although there was little seasonal change in standing stock, production was quite variable, with minima in winter and summer, a large spring bloom, and a small autumn pulse.

The major influence of Columbia River water on phytoplankton production appeared to be in the timing of events in the seasonal cycle. Phytoplankton development was noticeably affected by differences in the depth of the mixed layer and the sharp pycnocline during summer. However, total annual production both inside and outside the plume was similar ($60 \text{ g C m}^{-2} \text{ yr}^{-1}$). The nutrients introduced by river water appeared to be spent in high-production areas immediately off the mouth of the river.

The seasonal variation of C^{14} uptake-chlorophyll a ratios was marked. Low values occurred during winter, and a maximum occurred during the spring bloom. "Dead" or inactive chlorophyll appeared to be negligible at all times, judging from regressions of these relationships.

There is little information on the effects on plankton of large freshwater discharges into oceanic areas. However, it may be expected that the effect of the Columbia River discharge on the distribution and activity of plankton organisms will be marked and will vary seasonally with the amount and quality of discharge and its subsequent distribution.

The primary objective of this paper is to relate the standing crop and production of plankton to seasonal variations in the distribution of Columbia River effluent. (A.A.-modified)

Keywords: primary productivity, chlorophyll a, phytoplankton, Washington, Oregon

II-C-15

Riley, G.A. 1956. Production and utilization of organic matter---oceanography of Long Island Sound. Bulletin of the Bingham Oceanographic Collection 15:324-344.

The observed distribution of oxygen and phosphate was used to calculate the net biological rates of change of these elements on a seasonal basis. With the aid of experimental data and some arbitrary assumptions, the net changes were converted to estimates of total plant production and utilization of organic matter by various components of the marine association.

The total annual fixation of carbon by photosynthesis is estimated to be about 470 g/m². Over half of it is consumed in phytoplankton respiration. Of the estimated 205 g C/m² available for the remainder of the population, 26 percent appears to be used by that part of the zooplankton taken with a No. 10 net, 43 percent by microzooplankton and bacteria in the water column, and 31 percent by the benthic fauna and flora.

Although plankton concentrations are large, Long Island Sound does not appear to be superior in total productivity to adjacent open coastal waters. Findings indicate that phytoplankton production in Long Island Sound is at least twice as great as that in the English Channel, but it appears to be used less efficiently by the animal population. (A.A.)

Keywords: productivity, marine organisms, detritus, plankton, Long Island

D. Mangrove, Coastal Swamp, and Seagrass Productivity Studies

II-D-1

Golley, F.B., H.T. Odum, and R.F. Wilson. 1962. The structure and metabolism of a Puerto Rican red mangrove forest in May. Ecology 43:9-19.

One major community type little studied from the functional viewpoint is the tropical mangrove swamp. This study reports measurements of structure and metabolism for a representative red mangrove community of the terrestrial type on the southern shores of Puerto Rico. The study forest had not been disturbed since 1954 and was representative of other red mangrove forests in Puerto Rico.

Various methodologies were described which tended to quantify environmental properties, vegetational structure, animal densities, and the metabolism of principal components. A metabolic budget for one average day in May was compiled.

With a total gross production and respiration exceeding $8 \text{ g C/m}^2/\text{day}$ or about $16 \text{ g organic matter/m}^2/\text{day}$, the red mangrove is more fertile than most marine and terrestrial communities. (L.H.)

Keywords: mangrove, primary productivity, metabolism, Puerto Rico

II-D-2

Miller, P.C. 1972. Bioclimate, leaf temperature, and primary production in red mangrove canopies in South Florida. *Ecology* 53:22-45.

A model of primary production and transpiration of forest canopies was developed from the energy-budget equation of individual leaves to clarify some of the physical processes affecting primary production. The model calculates hourly vertical profiles of temperature, transpiration, respiration, and gross and net photosynthesis of both sunlit and shaded leaves and calculates appropriately weighted totals for the hourly water loss and gross and net photosynthesis for each level in the canopy. The model includes variation in leaf resistances caused by changes in absorbed solar radiation and changes in leaf water deficit and also takes into account the interdependence of the infrared profiles and the leaf-temperature profiles within the canopy. The model was tested with data collected on red mangrove (Rhizophora mangle Roxb.) forests. Canopy structure and the daily courses of solar and infrared radiation, air temperature, humidity, wind, and ground temperatures were measured and used as input data for the model. The model produced realistic leaf temperatures, leaf resistances, transpiration rates, and primary production rates and was used to indicate the relative importance of environmental variables in influencing leaf temperature, transpiration, and primary production. (A.A., excerpt)

Keywords: mangrove, primary productivity, energy-budget, Florida

II-D-3

Conner, W.H. 1975. Productivity and composition of a freshwater swamp in Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge. 85 pp.

This is a report on an October 1973 to October 1974 study of the productivity and composition of the freshwater swamp in the Lac des Allemands area, which is in the upper drainage basin of the Barataria Bay system. The productivity of Barataria Bay is well documented. The influx of freshwater from the swamp is critical to the estuarine nursery areas, which are dependent upon the balance between fresh and salt waters. Also, nutrient cycles and detrital chains within the estuary are enhanced by the import of nutrients and organic matter from the swamp.

Net productivity was determined from measurements of litter-fall and stem growth of woody species and harvest samples of annual herbaceous understory at two sites. Annual stem growth was calculated from biomass estimates on two different dates. The annual increase in stem biomass was 800 g dry wt/m² for the bottomland hardwood site (BLH) and 500 g dry wt/m² for the baldcypress-water tupelo site (CT). Litter-fall was 574 g dry wt/m²/yr for BLH and 620 g dry wt/m²/yr for CT. Harvest samples within the two plots yielded 200 g dry wt/m² and 20 g dry wt/m² for BLH and CT, respectively. Minimum net primary production was calculated as the sum of the three and yielded 1574 g dry wt/m²/yr for BLH and 1140 g dry wt/m²/yr for CT.

The author points out that his original estimates were low because he did not take into account understory production and insect grazing. Thus, he made estimates of maximum herbaceous production and insect consumption using values from the literature. Herbaceous production was estimated to be equal to 312 g dry wt/m²/yr at both sites, and caterpillar consumption was estimated at 47 g dry wt/m²/yr for BLH and 84 g dry wt/m²/yr for CT. Corrected total primary productivities based on these estimates were 1733 g dry wt/m²/yr for BLH and 1516 g dry wt/m²/yr for CT.

A literature review of biomass and productivity studies of swamps and forests is provided. (J.B.)

Keywords: primary productivity, freshwater swamps, nutrient cycles, detritus, Louisiana

II-D-4

Carter, M.R., L.A. Burns, T.R. Cavinder, K.R. Dugger, and P.L. Fore. 1973. Ecosystems analysis of the Big Cypress Swamp and estuaries. EPA-904/9-74-00. Environmental Protection Agency, Athens, Georgia. 379 pp.

This was a 2-year study to obtain biological and hydrological information for objective planning of the wise use of south Florida's land, water, wildlife and fisheries resources. Field investigations during 1971-1972 intensively examined the details of biotic community interactions with hydrologic conditions of disturbed and relatively unaffected regions of the Big Cypress Swamp and contiguous tidal wetlands and estuaries. Process studies and experimental and manipulation models were formulated for the various components of the ecosystem. Study results demonstrate the total dependence of the South Florida ecosystem on the hydroperiod. Canal drainage of upland wetlands, which include cypress swamps and wet-prairies, effected a ten-fold decrease in primary productivity. Drainage also effected a thinning of the forest canopy and induced a reduction in the rate of forest litter decomposition,

resulting in a buildup of litter as increased fuel sources for destructive wildfires. (A.A.)

Keywords: primary productivity, planning, ecosystems, estuaries, Florida

II-D-5

Jones, J.A. 1968. Primary productivity by the tropical marine turtle grass, Thalassia testudinum Koig, and its epiphytes. Ph.D. Thesis. University of Miami, Coral Gables, Fla. 206 pp. (Diss. Abstr:29-3637-B)

The measurement of primary productivity by aquatic spermatophytes is complicated by environmental changes, tissue destruction, and possible wound metabolism for experiments on uprooted plants, or the interactions between the plant and the rest of the community for in situ experiments. Three approaches to the determination of primary productivity have been tested on the marine turtle grass, Thalassia testudinum, and its epiphytes. One method measures production rate under nearly natural community conditions. A second is used to determine the potential production by an individual isolated spermatophyte. The third approach investigates the contribution by the epiphytic flora. The first two methods involve the polarographic determination of the change in dissolved oxygen concentration due to productivity by the plants under bell jars or within chambers. Differential manometry has been adapted to the determination of changes in gas volume due to productivity by the epiphytes.

Gross productivity by Thalassia may reach about 1.0 ml O₂/g·hr. Mean respiration rate is about -0.15 ml O₂/g·hr. Maximum net production is about 700 ml O₂/m²·hr. with a corresponding respiration rate of about -100 ml O₂/m²·hr. Production rates are primarily dependent upon irradiance and standing crop. Respiration rates are primarily dependent upon temperature and standing crop.

Total annual production by a dense community is about 1700 L O₂/m², 900 gc/m², or 18 kg live plant tissue per square meter. One-fourth to one-third of the community metabolism may be attributable to the epiphytes, which may constitute the only readily available source of food to the herbivores of the community. (A.A.)

Keywords: primary productivity, turtle grass, Florida, Thalassia

II-D-6

Zieman, J.C. 1975. Quantitative and dynamic aspects of the ecology of turtle grass, Thalassia testudinum. Pages 541-562 in L.E. Cronin, ed., Estuarine research, Vol. 1. Academic Press, New York.

In recent years the vast beds of sea grasses bordering the temperate and tropical coastlines have been recognized as a valuable resource. Techniques were developed to measure the production and seasonal dynamics of Thalassia testudinum, the dominant marine grass of the Caribbean. Conventional productivity measures are subject to error from gas storage within the leaves. Production of leaf material varied from 0.3 to 10.0 g dry wt m⁻² day⁻¹ in the south Florida area, with mean values of 2.3-4.0 g m⁻² day⁻¹. Leaf growth rates averaged 2-5 mm day⁻¹ with maximum values exceeding 10 mm day⁻¹. The rhizomes of Thalassia were found 5-25 cm in the sediment, and roots penetrate to 4-5 m. Leaves constituted 15-22 percent of the total plant biomass, and leaf standing crops were found from 30-650 g dry wt m⁻², with average values of 126 and 280 in inshore and offshore waters, respectively. Leaf densities averaged 3460-4300 blades per m². Standing crop varied by about 50 percent throughout the year, with leaf decreases during flower and fruit production and again in the fall. Thalassia produced about 6.8 crops of leaves per year. Few were directly grazed. The leaves decayed rapidly, losing 65 percent of their original weight in seven weeks. Drying and agitation greatly accelerated decomposition. Turtle grass contributes to the maintenance of the high production of estuaries in many other ways also. (A.A.)

Keywords: turtle grass, Thalassia testudinum, seagrasses, primary productivity, Florida

E. Growth Factors, Nutritive Value, and Weight

II-E-1

Joanen, T., and L.L. Glasgow. 1965. Factors influencing the establishment of wigeongrass stands in Louisiana. Pages 78-92 in Proceedings of the nineteenth annual conference of the Southeastern Association of Game and Fish Commissioners.

A study of the factors that influence the establishment of natural and artificial stands of wigeongrass (Ruppia maritima) was conducted on Rockefeller Refuge during 1962-63. Physical, chemical and biotic factors were investigated; growth was measured monthly and germination tests of wigeongrass seed were carried out.

Physical factors such as turbidity, fluctuating water levels, and water depth were found to be controlling factors in the establishment

of new stands and also to the development and production of mature stands of wigeongrass. Correlations were found between water depth, turbidity, and vegetative production. The greatest production was obtained at the 24-inch water level. A generalized range of turbidity which will allow wigeongrass growth in ponds with water depths less than 24 inches, as found in this study, is from 25 ppm to 54 ppm.

Wigeongrass was observed growing in a wide range of salinities from 2,075 ppm to 18,500 ppm in the study ponds and 1,160 ppm to 19,000 ppm in the experimental tanks. There was no correlation between chlorides and growth of wigeongrass. Wigeongrass was found to have two growing seasons that are controlled by a temperature range of 18.5°C to 30°C. When the temperature was above or below these figures, growth apparently ceased.

Water quality and soil chemistry, other than the factors mentioned above, proved to be of little significance in influencing the growth of wigeongrass. (G.S.)

Keywords: wigeongrass, primary production, Louisiana

II-E-2

Steward, K.K., and W.H. Ornes. 1973. The autecology of sawgrass (Mariscus jamaicensis) in the Florida Everglades. National Park Service, Atlanta, Georgia, Ecological Report No. DI-SFEP-74-04. 10 pp.

Estimates were obtained for the standing crop, plant density, stem length, leaf numbers, growth rate, and nutrient relationships in tissue, soil, and water for typical stands of sawgrass in the Florida Everglades. The nutrient requirements were determined to be low in comparison to other species of Everglades macrophytes. The apparent low nutrient requirements of sawgrass may partially explain its dominance in the marsh community. (J.B.)

Keywords: primary productivity, sawgrass, Florida (Everglades)

II-E-3

Steward, K.K., and W.H. Ornes. 1973. Investigations into the mineral nutrition of sawgrass using experimental cultural techniques. National Park Service, Atlanta, Georgia, Ecological Report No. DI-SFEP-74-05. 11 pp

The nutrient levels of sawgrass plants (Cladium jamaicense) were determined for an area in the Florida Everglades, and experimental culture techniques were used to determine the response of sawgrass to nutrient enrichment. There appeared to be an optimum phosphorus

level for the tissues, since higher levels inhibited dry-matter production. This indicates that serious consequences might result from the discharging of nutrient-rich waters into the Everglades marshes. (J.B.)

Keywords: productivity, sawgrass plants, nutrients, Florida (Everglades)

II-E-4

Broome, S.W. 1973. An investigation of propagation and the mineral nutrition of Spartina alterniflora. Ph.D. Thesis. North Carolina State University at Raleigh. 126 pp. (Diss. Abstr. 34:4330-B)

Germination studies of seed of Spartina alterniflora Loisel collected from several locations along the coast of North Carolina have shown that this grass produces large quantities of viable seed. The germination percentage is affected by maturity of the seed; consequently, they should be collected as near the shattering stage as possible. Seed should be placed in cold storage at 2-4° C. soon after harvesting and submerged in estuarine water within a month to retain viability over winter.

Field experiments have shown that direct seeding can be an effective method of establishing new stands of S. alterniflora on dredge spoil. Seedlings can be expected to survive only in the upper half of the natural elevation range of S. alterniflora at a particular location. The aboveground standing crop of plant material produced from seed in one growing season may approach the annual production of long-established marshes.

Regression analysis was used to examine relationships between nutrient concentration in the plant tissue and/or soil, and productivity of S. alterniflora in natural stands. Variables found to be negatively associated with yield include salinity of the soil solution, manganese concentration in the plant tissue and soil, and sulfur concentrations in the plant tissue. Concentration of phosphorus (P) in the plant tissue and soil were found to be positively related to yield. Regression equations for predicting standing crop of nutrients from dry weight of the grass are presented.

Increased growth of S. alterniflora in response to applications of nitrogen (N) and P fertilizers indicates that the productivity of salt marshes is limited by the supply of these nutrients. Yields were increased significantly by additions of N to a salt marsh growing on a substrate of sand and increased about threefold when both N and P were supplied. In a marsh developed on finer textured sediments, N fertilizer doubled the standing crop of short Spartina, but there was no response to P. At least a part of the reason for the low productivity of short

Spartina is due to the lack of available N. There was no response to applications of iron to support previous speculation that iron might be a limiting factor in growth.

Nitrogen and P fertilizers were also shown to enhance growth of seedlings and transplants artificially established on sandy dredge spoil. This may be of practical benefit since establishing a vegetative cover rapidly may be critical in stabilizing an area. (A.A.)

Keywords: productivity, Spartina alterniflora, mineral nutrition, North Carolina

II-E-5

Pomeroy, L.R., R.E. Johannes, E.P. Odum, and B. Roffman. 1969. The phosphorus and zinc cycles and productivity of a salt marsh. Pages 412-419 in D.J. Nelson, ed., Proceedings of the Second National Symposium on Radioecology, U.S. Atomic Energy Commission, Washington, D.C.

By synthesizing the results of two field experiments using phosphorus (P) and zinc (Zn) with earlier work on Georgia salt marshes, the cycles of the elements P and Zn are quantitatively described. Marsh grass and sediments dominate both cycles. The uppermost meter of sediments contains enough P to support Spartina production for 500 years and enough Zn for 5000 years. Spartina production removes P and Zn from the subsurface sediments and introduces them into the water (via bacterial utilization of dead Spartina and subsequent utilization of the bacteria by detritus feeders) at a rate that replaces total water P in a month and total water Zn in a year. A significant part of the P is exported from the marsh in organisms and detritus. The P and Zn in the estuarine water are in equilibrium with plankton, bacteria, and surface sediments. The equilibrium strongly influences the sediments. The transfer of P and Zn from the dry sediments to the water by Spartina explains the high concentration of these elements in the water of marshy estuaries. (L.H.)

Keywords: salt marsh, productivity, mineral nutrition, Spartina, Louisiana

II-E-6

Thayer, G.W. 1974. Identity and regulation of nutrients limiting phytoplankton in the shallow estuaries near Beaufort, North Carolina. Oecologia 14:75-92.

Enrichment experiments to test the hypothesis that nitrogen was the prime limiting nutrient and experiments to determine whether microbial competition for nitrogen and phosphorus might limit the availability of these nutrients to the phytoplankton are described. Inorganic nutrients

limiting phytoplankton production in the shallow estuarine system near Beaufort, North Carolina, were identified. Nitrogen was the primary limiting nutrient and was found to be phosphorus limiting at times. Samples receiving a complete enrichment medium plus organic substrates poor or lacking in nitrogen and phosphorus showed no significant increase in relative photosynthesis over unenriched controls, even though there was a significant decrease in the nitrogen and phosphorus concentrations in the enriched samples. This suggested that microbial immobilization of nitrogen and phosphorus during decomposition of organic matter may limit nutrient availability to phytoplankton and in part account for the general paucity of inorganic nutrients present in this shallow system. The estimated amounts of carbon, nitrogen and phosphorus entering the estuarine system in the form of partially decayed Spartina alterniflora each year are given. Data suggested that an annual cycle in nutrient concentration in the estuarine system in part may result from shifts in the equilibrium between microbial immobilization and remineralization. (A.A.)

Keywords: phytoplankton, estuaries, nutrients, North Carolina

II-E-7

Williams, R.B. 1973. Nutrient levels and phytoplankton productivity in the estuary. Pages 59-89 in R.H. Chabreck, ed., Proceedings of the coastal marsh and estuary management symposium. Louisiana State University, Baton Rouge.

Phytoplankton are ubiquitous photosynthetic plants with a potential for a large production from a small standing crop due to rapid cell division and an absence of non-photosynthetic tissue. Maximum daily rates reported for estuarine phytoplankton production are 22.6 (gross) and 16.4 (net) g C/m². Annual rates range from 100 to over 546 g C/m² for gross production, and from -11 to 220 g C/m² for net production. In shallow estuaries, rates of production tend to follow the seasonal cycle in water temperature. Maximum rates of production per unit volume usually occur near the heads of estuaries and maximum rates of production per unit area near the mouths. In estuaries along the southeastern U.S. coast, rooted plants may often outproduce the phytoplankton. Nutrient enrichment studies indicate the available nitrogen commonly limits estuarine and coastal phytoplankton production; there is normally ample phosphorus relative to nitrogen. Physiological studies reveal, however, that many species of phytoplankton can thrive at the inorganic nitrogen concentrations commonly present in estuaries. It is likely that the actively photosynthesizing species are adapted to existing nutrient conditions. Nutrient enrichment causes a shift to species adapted to higher nutrient levels as well as an increase in phytoplankton biomass and production. (A.A.)

Keywords: nutrient levels, phytoplankton, productivity, estuaries, U.S. general

II-E-8

Burkholder, P.J. 1956. Studies on the nutritive value of Spartina grass growing in the marsh areas of coastal Georgia. Bulletin of the Torrey Botanical Club 83:327-334.

Extensive low areas along the coast of Georgia are covered with marsh grasses. Among these grasses, Spartina alterniflora Loisel contributes on a large scale to primary productivity in the marshes and shallow estuaries of the region. Especially luxuriant growth of this dark green grass, oftentimes attaining a height of six feet, occurs in the low marshes, along riverbanks and on the shores of islands. The grass of high marshlands is yellow-green in color, tougher, and generally less than two feet in height. The Spartina main crop grows during a long season from March to October. In protected places with southern exposure, however, the grass may show growth of tender green shoots even during the winter months. The crop apparently disintegrates slowly during the year or two following its maturation in the fall. Microbial conversion of grass and its consumption by small herbivores lead into the complex cycle of nutrition which supports crustaceans, fish, and fowl, all of which abound in the region.

General observations of the extensive productivity and potential uses of Spartina in the coastal regions of Georgia prompted the collection of samples of the marsh grass for analysis of its nutritive content, with particular reference to its B vitamins and amino acids, known to be essential for growing animals. The study found that proximate analysis of young Spartina yields values similar to those that have been published for Coastal Bermuda grass. The following data (percent dry basis) represent the contents of growing shoots of Spartina: fat, 2.98; protein, 13.24; crude fibre, 29.75; ash, 12.83; and nitrogen-free extract, 40.20. The therms per pound are 1.68. Weathered shoots, collected in August from growth of the preceding year, show loss of their leaves, and greatly lowered content of fat, protein, calcium and phosphorus.

The ten essential amino acids, required for growth of the rat and man, constitute about 15 percent of the protein of Spartina. Biological value of the protein is calculated to be deficient as a nitrogen supply for marine animals, and it is suggested that microbial conversion of the grass may act as a transformer to step up the potential value of the pool of protein in the sea. (J.B.)

Keywords: productivity, nutrients, Spartina, Georgia

II-E-9

Burkholder, P.R., L.M. Burkholder, and J.A. Rivero. 1959. Some chemical constituents of turtle grass, Thalassia testudinum. Bulletin of the Torrey Botanical Club 86:88-93.

This study was initiated in order to find out more about the magnitude, chemical composition, and possible value of Thalassia to the marine life of tropical regions. Some simple comparisons of proximate analyses were made between Thalassia and other primary crops of grasses from Georgia, and phytoplankton from Long Island Sound.

Determinations were made for several parameters, such as protein, fat, ash, and crude fibre, on various materials. It was found that turtle grass, Thalassia testudinum, is abundant in the shallow, well-illuminated waters of Puerto Rico and other tropical areas. The standing crop of Thalassia, ranging up to about 33 tons per acre, provides shelter for many species of animals and contains large amounts of basic foodstuffs in the form of proteins (13 percent), crude fibre (16 percent), and other carbohydrates (36 percent).

Quantitative determinations of aspartic and glutamic acids and ten essential amino acids were performed. Among the 12 amino acids assayed, the most abundant were aspartic and glutamic acids, arginine, lysine and leucine. Tryptophan was relatively scarce.

The quantitative distribution of marine bacteria, adjacent to and in beds of Thalassia, was studied in a channel lying between Magueyes Island and the mainland near La Parguera. It was determined that marine bacteria convert organic constituents of Thalassia to microparticulate food suitable for protozoa, which are in turn available to smaller and larger animals. Microscopic studies on microbial decomposition of non-sterile, macerated Thalassia leaves indicated that very large populations of bacteria rapidly developed, and that these, in all experiments with mixed cultures, were promptly followed by tremendous growths of ciliated protozoa. It seems probable that many predatory animals, which live in the meadows of turtle grass, may be feeding upon microbial populations of bacteria, ciliates, and other transformers, which are supported by chemical constituents of Thalassia. Some fishes, notably the ballahoo, may feed almost exclusively on leaves of Thalassia at certain times. It seems probable, however, that the greatest use of the primary production of turtle grass is mediated through microbial conversions of organic matter in the leaves, rhizomes and roots. (H.D.)

Keywords: turtle grass, productivity, phytoplankton, Puerto Rico

II-E-10

Turner, R.E., and J.G. Gosselink. 1975. A note on standing crops of Spartina alterniflora in Texas and Florida. University of Texas Contributions in Marine Science 19:113-118.

A late summer (August 19-24) survey of eight Spartina alterniflora marshes in Texas and Florida was conducted in 1974. The authors found that the live biomass is equivalent to or slightly greater than that found on the north Atlantic coast, but the dead biomass is considerably greater. The relationships of grass height to biomass that were described for North Carolina (Williams and Murdoch, 1969) and Rhode Island (Nixon and Oviatt, 1973) were also valid for the Gulf marshes. The slope of the regression equations appears to increase with decreasing latitude and reflects changes in stem density and weight. (A.A., modified)

Keywords: Spartina alterniflora, biomass, Texas, Florida

II-E-11

Turner, R.E. 1976. Geographic variations in salt marsh macrophyte production: a review. University of Texas Contributions in Marine Science 20:47-68.

A review of salt marsh macrophyte production measurements supports the conclusion of a north-south gradient which parallels solar energy inputs at a 0.20-0.35% net conversion efficiency. There is considerable variation within and among marshes. Methods previously employed to measure salt marsh macrophyte production have generally underestimated the actual net above-ground production because of an inability to account for the turnover of live material between sampling periods. Turnover apparently increases with decreasing latitude and may be equal to annual changes in standing live biomass. The effect of other factors influencing production are discussed and a detailed data review presented. (A.A.)

Keywords: Spartina alterniflora, salt marsh, geographic variation, biomass

III. DETRITUS IN THE FOOD CHAIN

A. Theoretical Perspectives

III-A-1

Melchiorri-Santolini, U., and J.W. Hopton, eds. 1972. Detritus and its role in aquatic ecosystems. Memorie dell'Istituto italiano di idrobiologia, 29 Suppl. 540 pp.

The purpose of the IBP UNESCO Symposium on Detritus and its role in aquatic ecosystems was to present to investigators interested in aquatic environments an up-to-date review of the diversity of work that is being undertaken to clarify the role of detritus and to indicate the variety of information that has been obtained.

Forty-five scientists from twelve countries met in Pallanja, Italy, from May 23-27, 1972, to explore this topic. Twenty-four papers were presented and discussed on the subject of detritus in aquatic ecosystems. A wide area was covered, ranging from specific problems such as the attachment of bacteria to detrital particles, to very expanded problems such as carbon flow in whole ecosystems and detrital participation in the flow. Abstracts for two of these papers are presented elsewhere. (See III-A-2 and III-A-3.) (H.D.)

Keywords: detritus, aquatic ecosystems

III-A-2

Mann, K.H. 1972. Macrophyte production and detritus food chains in coastal waters. Pages 353-383 in U. Melchiorri-Santolini and J.W. Hopton, eds., Detritus and its role in aquatic ecosystems. Memorie dell'Istituto italiano di idrobiologia, 29 Suppl.

This paper reviews the distribution, productivity, and detritus-forming activities of marine macrophytes (including marsh plants) on a global scale. In reviewing previous productivity studies, the author points out that an annual production of 500 to 1,000 g C/m² is typical of coastal macrophytes (kelps, sea grasses, rock weeds, marsh grasses, and mangroves). These may be compared with world averages for phytoplankton production: 50 g C/m² per year for the open ocean and 100 g C/m² per year for the coastal zone. The macrophyte fringe of the oceans has an intensity of production which may be up to 40 times the intensity of production in the open ocean. Previous studies suggested that the productivity of Spartina alterniflora marshes decreased regularly with latitude; however, in his own research on the Petpeswick Inlet in Nova Scotia, the author found that annual production averages about 290 g C/m², one of the highest figures recorded north of Georgia.

Among the marine fishes of the world, the use of detritus as a major source of food is not common. The available evidence suggests

that microorganisms are the most important consumers of marine macrophytes and that detritus-feeding invertebrates derive their nourishment mainly by stripping the microorganisms from the plant material as it passes through their guts. The fecal pellets may be recolonized by microorganisms and the process repeated until all the plant material has been utilized. W. E. Odum's opinion is cited to the effect that the important consumers of detritus in the estuary are the invertebrates and that fish production is sustained primarily by predation on these detritus-feeding invertebrates. Also, the export of detritus in suspension to the coastal waters makes a substantial contribution to the planktonic food chains. (J.B.)

Keywords: productivity, detritus, macrophytes, food chain, coastal waters

III-A-3

Saunders, G.W. 1972. Summary of the general conclusions of the symposium. Pages 533-540 in U. Melchiorri-Santolini and J.W. Hopton, eds., *Detritus and its role in aquatic ecosystems*. Memorie dell'Istituto italiano di idrobiologia. 29 Suppl.

The IBP UNESCO Symposium on detritus and its role in aquatic ecosystems provided a general consensus in several areas. It was recognized that detritus is quantitatively important in most aquatic ecosystems, both freshwater and marine. Detritus tends to be present in greater quantities than living organisms although this is not always true. One major problem considered was that of isolating and quantitatively measuring the amount of detritus. A method for isolating detritus from other particles suspended in water has not yet been discovered.

It was also shown that adsorption of nutrient substances, attachment of bacteria, and assimilation of the nutrient substrate on the surfaces of particles proceeded in a very complicated manner and could be important in determining the distribution of bacteria in the water and the rate at which bacterial metabolism might occur. Dead macrophytic plant material provides an abundant nutrient source on which luxurious growths of bacteria occur.

Detrital particles in the deep-sea zone were shown to undergo only very slow decomposition and represent a very small percentage of particulate matter produced in the open ocean. The settling rate of particulate matter, both dead and living, is a major process involved in redistributing the potential energy produced initially by photosynthesis. If the detritus is slow in settling, more soluble organic matter will be released in a unit volume of water than if the detritus settles rapidly.

It was shown that detritus has, in general, a relatively slow decomposition rate, and if it is ingested by animal organisms it may not be so easily assimilated as it is by microorganisms. One would expect,

therefore, to find more organic detritus in an aquatic system than living biomass. The decomposition of organic detritus can be considered as an interaction between detrital particles and bacteria. The rate of change is given as a bimolecular second order reaction. A mathematical formula is given for this process, although it is stressed that the function is not relatively simple. It is further expressed that additional information and study in the areas of grazing, sedimentation, and/or physical transport would be beneficial in determining rate of change in detritus concentration. Study is needed in various areas in order to provide a general idea of the importance of detritus in any aquatic system. (H.D.)

Keywords: detritus, nutrients, aquatic ecosystems

III-A-4

Dickinson, C.H., and G.J. Pugh, eds. 1974. Biology of plant litter decomposition. Academic Press, New York, 2 vols.

In the past much emphasis has been placed on finding out what organisms occur in particular processes such as litter decomposition and in habitats such as soil. Within some disciplines the emphasis is moving toward autecological studies. Recent volumes have tended to be concerned with particular groups of organisms in specific habitats, such as fungi in soil, animals in soil and marine bacteria. We now see the need to synthesize the knowledge that has been obtained during studies of specific groups of organisms and to draw attention to their interrelationships in plant litter decomposition.

A central process in the life cycle of all green plants is the decomposition of their remains. During this decomposition many complementary and/or competing organisms are active. Frequently the processes of decomposition begin before the plant part senesces and the sequence of organisms involved is related to the type of plant material and the environment. Decomposition is then conditioned by the nature of the plant tissues, the range of organisms able to decompose these tissues, and the environment.

The arrangement of the chapters in this book follows the above pattern, and the quantity of material involved has made it necessary to divide the book into two volumes. In Part I, which constitutes Volume 1, the primary emphasis is placed on the type of litter. In this context, litter is taken to include all plant remains, which range from still standing dead trees to the decomposing hyphae of fungi and cells of bacteria. The organisms involved in decomposition processes are discussed in Part II, which forms the first part of Volume 2.

The second part of Volume 2, Part III, is concerned with the environmental conditions under which breakdown occurs over the whole global surface. Terrestrial, freshwater and marine environments are considered

separately. A further two aspects are anthropocentric: agriculture, with an emphasis on the importance of the saprophytic activity of plant pathogenic fungi; and the increasingly important composting of urban waste. One article from Part III has been chosen for review in this bibliography. (See III-A-5.) (Author's summary and J.B.)

Keywords: marsh plants, decomposition, plant litter

III-A-5

Perkins, E.J. 1974. Decomposition of litter in the marine environment. Pages 683-722 in C.H. Dickinson, ed., *Biology of plant litter decomposition*, Vol. 2. Academic Press, New York.

This chapter is part of a 2-volume, comprehensive study of the decomposition processes for all types of plant litter. The chapter covers the marine and terrestrial sources of litter in the sea, the amount of litter in estuaries, the transport and deposition of litter, and the breakdown of litter. The role of marshlands in litter production is discussed. (J.B.)

Keywords: primary productivity, plant litter, estuaries

III-A-6

Darnell, R.M. 1967. The organic detritus problem. Pages 374-375 in G.H. Lauff, ed., *Estuaries*. American Association for the Advancement of Science, Washington, D.C.

The literature dealing with the organic detritus problem is described as diffuse, widely scattered, and written in a variety of languages. Thus, it is difficult for the individual worker to gain an overall insight into the complexities of the subject. Further, much of the important detritus work has not been carried out in estuaries. It is, therefore, necessary to transpose and translate this knowledge into the estuarine context.

Organic detritus is defined as all types of biogenic material in various stages of microbial decomposition that represent potential energy sources for consumer species. Thus, organic detritus includes all dead organisms as well as the secretions, regurgitations, excretions, and egestions of living organisms, together with all subsequent products of decomposition which still represent potential sources of energy.

A brief history of the research that has been done on organic detritus is presented. The author feels that with the advent of radioactive tracer techniques and germfree procedures it is now possible to approach this subject experimentally and to provide quantitative data rather than speculative hypotheses.

It is noted that consumer nutrition is only one aspect of the organic detritus problem. Many organic compounds released into the aquatic environment have been shown to exert specific influences upon various species. Such influences include growth stimulation or inhibition, attraction or repulsion, and so on. Through its contributions to turbidity, sedimentation, and chemical alteration of the environment, organic detritus influences every major process active in aquatic communities. (H.D.)

Keywords: productivity, detritus, estuaries, food chain

III-A-7

Russell-Hunter, W.D. 1970. Aquatic productivity: an introduction to some basic aspects of biological oceanography and limnology. Collier-Macmillan, London. 306 pp.

This book presents basic aspects of faunal productivity in aquatic environments. Applied and theoretical considerations are discussed. Basic biogeochemistry of organic cycles and biomass transfer between different trophic levels is illustrated using marine and fresh water examples. Factors controlling primary productivity and food chains in various ecosystems are discussed.

The author indicates that shallow coastal waters and semienclosed areas of the sea can be characterized as sometimes more productive, and always more variable in productivity, than waters of the open ocean at the same latitude. In shallow coastal waters, the bottom frequently supports a rich fauna, the benthic animals alone often amounting to a standing-crop biomass in excess of 100 grams of living tissue in each square meter of mud. In these circumstances, there are fast local cycles of nutrient salts and rapid turnover of detritus.

Waterborne detritus and the local crops of attached diatoms and microscopic algae are important contributors to productivity in estuaries and other brackish-water habitats. The length of time spent in recirculation within the estuary may be of great importance in allowing time for bacterial decomposition and proportionate change. This can involve not only complete decomposition, which provides increased nutrient salts for green plants, but also partial decomposition, which renders detritus from marsh plants more suitable for animal nutrition. (H.D.)

Keywords: productivity, marine organisms, freshwater organisms, food chain, seagrasses, algae

III-A-8

Barnes, R.S. 1974. Estuarine biology. Edward Arnold, London. 76 pp.

This booklet views the biology of estuarine organisms in the context of their environment as a whole. It also introduces to a general audience some of the more recent advances in our knowledge and understanding of estuaries. The third section is concerned with the food web and contains a concise description of the relationship between detritus production in the salt marshes and the eventual assimilation of nutrients by the higher aquatic animals. (J.B.)

Keywords: estuarine organisms, food web, detritus, salt marshes

III-A-9

Odum, W.E., J.C. Zieman, and E.J. Heald. 1973. The importance of vascular plant detritus to estuaries. Pages 91-114 in R.H. Chabreck, ed., Proceedings of the coastal marsh and estuary management symposium. Louisiana State University, Baton Rouge.

The role of vascular plant detritus in estuaries is discussed. Sources and amounts of annual net production are compared for marsh grasses, sea grasses and mangroves. The processes and mechanisms of degradation and export are examined and the utilization of detritus by consumers is described.

In most shallow estuaries, there is a group of detritus consumers made up of few species but many individuals. Included in this group are amphipods, mysids, cumaceans, ostracods, chironomid midge larvae, harpacticoid and planktonic copepods, snapping shrimp, caridean shrimp, penaeid shrimp, crabs, filter feeding bivalves and a few species of fishes. All of these derive a significant amount of their nourishment from the ingestion of vascular plant detritus along with small quantities of fresh algae. Moreover, fecal material extruded by one organism in this group may be re-ingested a short time later by another species, and the entire process of microbial enrichment and subsequent digestion by the detritus consumer will be repeated. It is these organisms which are responsible for supplying the critical link between detritus production and the production of higher consumers. (A.A.)

Keywords: vascular plants, detritus, estuaries, aquatic invertebrates, fishes

III-A-10

Darnell, R.M. 1967. Organic detritus in relation to the estuarine ecosystem. Pages 376-382 in G.H. Lauff, ed., Estuaries. American Association for the Advancement of Science, Washington, D.C.

This paper explores the processes of biological decomposition of estuarine detritus and examines non-nutritive as well as nutritive roles. The author defines organic detritus as all types of biogenic material in various stages of microbial decomposition, which represents potential energy sources for consumer species. Two states are recognized: the particulate and subparticulate. The author discusses estuarine detritus in relation to turbidity, sedimentation, and nutrition.

It was determined that particulate organic detritus is everywhere abundantly available, that it is ingested in quantity by zooplankton, fishes, and benthic invertebrates, and that areas of zooplankton abundance are correlated with centers of detritus abundance rather than with phytoplankton abundance. Such results lead one to suspect causation, but whether the relation is direct or indirect is not yet known. There can be little doubt that in most estuaries particulate organic detritus is abundant and is consumed in great quantities.

The author concludes that most organic detritus is of vegetable origin. Since few of the larger estuarine consumers feed upon vegetation alone, the real primary consumers of the community are the microbial species (decomposers). Although the trophic efficiency of microbes has not yet been determined, it is apparent that some energy is lost in passage through the microbial scheme. Since most of the larger consumers of the estuarine community are omnivores, their relative trophic positions can be assigned only by determining the percentage contributions of energy from each food source. (H.D.)

Keywords: detritus, productivity, estuaries, decomposition

III-A-11

Heald, E.J., and W.E. Odum. 1969. The contribution of mangrove swamps to Florida fisheries. Proceedings of the Gulf and Caribbean Fisheries Institute 22:130-135.

The primary food source for aquatic organisms in many shallow estuaries, particularly those at lower latitudes, is not phytoplankton but vascular plant detritus. In south Florida, the red mangrove (Rhizophora mangle) and turtle grass (Thalassia testudinum) are the primary sources of detritus.

This paper discusses the importance of mangrove swamps to the ecology of south Florida estuarine areas from the perspective of detritus production. The pathways by which the primary production of these plants is ultimately utilized by species of commercial value are described.

The data upon which the discussion is based were gathered during 1967 and 1968 in the North River estuarine system of Everglades National Park.

The study indicates that the first link in the food web is provided by bacteria and fungi, which convert the relatively undigestible lignin and cellulose of vascular plant tissue into a protein source that can be digested by higher organisms. The second link is composed of opportunistic omnivorous crustaceans such as amphipods, mysids, harpacticoid copepods, caridean and penaeid shrimp along with chironomid midge larvae and a few omnivorous fishes such as the striped mullet, sheepshead minnow, and molly. All of these ingest large quantities of detritus particles with their loads of digestible microorganisms. Feeding on these detritus consumers are a large group of fishes, including all of the juvenile game fishes.

From the discussion, it is apparent that the production of game and food fish from mangrove systems such as the North River is directly linked to the production of vascular plant detritus in the form of decaying mangrove leaves, roots, bark, and wood. The production of phytoplankton and benthic and epiphytic algae in such an area is so much less than the production of mangrove detritus that the yield of gamefish must decline in proportion to mangrove destruction. (J.B.)

Keywords: mangrove swamps, food web, fisheries, estuaries, Florida

III-A-12

Odum, W.E., and E.J. Heald. 1972. Trophic analyses of an estuarine mangrove community. *Bulletin of Marine Science* 22:671-738.

Fringing the southwest coast of Florida is a mangrove belt that supports large populations of birds, gamefishes, and invertebrate species of commercial importance. A study was conducted between 1967 and 1969 in the North River basin of this mangrove region to determine the energy basis for this large population of animals and to delineate the route by which energy is transferred through the food web. Summaries of food habits for most of the fish and aquatic invertebrate species that occur in the North River mangrove ecosystem are given. In addition to study data on 10,000 analyses of stomach contents, information from other publications has been summarized where pertinent. Finally, for most species there is an estimate of relative importance in the North River system in terms of abundance. (A.A.-modified)

Keywords: mangroves, trophic analysis, estuaries, Florida

III-A-13

Hickling, C.F. 1975. Water as a productive environment. St. Martin's Press, New York. 203 pp.

This book is primarily concerned with the essential character of water movement. It treats the subject from an ecological viewpoint by following water from the hills and mountains down the path of gravity to the torrents and hill streams, thence to the rivers, lakes, artificial lakes and dams which are built to economize and use water, and so on to the estuaries.

The study of water is usually within the context of two disciplines: limnology, the study of inland waters which are usually fresh; and oceanography. The plan of this book involves both disciplines, showing logically how water supports life in abundance. Kinds of vegetation responsible for primary production, quantities produced, and how the primary production of material fuels the activities of successive levels of animal life, leading finally to the fishes which provide man with food and recreation, are discussed. (H.D.)

Keywords: estuaries, ecology, water, primary productivity

III-A-14

Odum, E.P. 1962. Relationships between structure and function in ecosystems. Japanese Journal of Ecology 12:108-118.

Ecology is defined as the study of the structure and function of ecosystems. Biological structure influences the pattern of energy flow, particularly the fate of net production and the relative importance of grazers and detritus consumers. The author cites three major aspects of function: (1) the energy flow through the ecosystems beginning with the incoming solar energy and passing through the successive trophic levels, (2) the cycling of nutrients, and (3) community regulation.

It is suggested that the basic pattern of functional change in ecological succession is the same in all ecosystems, but that the species composition, rate of change and duration of succession is determined by the physical environment and the resultant community structure. (H.D.)

Keywords: ecosystems, energy flow, productivity, detritus

B. Detritus Production

III-B-1

Reimold, R.J., J.L. Gallagher, R.A. Linthurst, and W.J. Pfeiffer. 1975. Detritus production in coastal Georgia salt marshes. Pages 217-228 in L.E. Cronin, ed., Estuarine research, Vol. 1. Academic Press, New York.

The change in quantity of dead material and the detritus production flux (instantaneous rate of disappearance) were measured at four-week intervals in three plant stands in Georgia salt marshes. Detritus production (areal rate of disappearance) was calculated from these data. The average standing crop of dead material was highest in Juncus roemerianus and lowest in short-form Spartina alterniflora. The detritus production fluxes were an average of $7 \text{ mg g}^{-1} \text{ day}^{-1}$ for tall-form S. alterniflora, $18 \text{ mg g}^{-1} \text{ day}^{-1}$ for short-form S. alterniflora and $7 \text{ mg g}^{-1} \text{ day}^{-1}$ for J. roemerianus. The average monthly detritus production of tall-form S. alterniflora (197.9 g m^{-2}) was significantly greater than short-form S. alterniflora detritus production (113.6 g m^{-2}). The average monthly J. roemerianus detritus production (188.4 g m^{-2}) was significantly greater than that in short-form but not that in tall-form S. alterniflora. Mean annual detritus production from the aerial portion of the plants (weighted for the percentage of the watershed occupied by each stand) was $1845.8 \text{ g m}^{-2} \text{ yr}^{-1}$ (A.A.)

Keywords: detritus, productivity, Georgia

III-B-2

De la Cruz, A.A. 1965. A study of particulate organic detritus in a Georgia salt marsh-estuarine ecosystem. Ph.D. Thesis. University of Georgia, Athens. 141 pp. (Diss. Abstr. 27:363-B)

In Georgia estuaries dominated by Spartina alterniflora marshes, organic detritus is the chief link between primary and secondary productivity, since only a small portion of net production of the marsh grass is grazed while in the living state. Six aspects of detritus were studied at the University of Georgia Marine Institute at Sapelo Island, namely: 1) origin and formation (i.e., decomposition) of organic detritus; 2) size distribution and standing crop of detritus particles and composition of total seston; 3) tidal transport of detritus in and out of a ten-hectare area of marsh drained by a single small tidal creek; 4) metabolism of detritus particles; 5) caloric and nutritive values of the different age and size particles; 6) heterotrophic utilization of organic detritus by the marsh and estuarine consumers.

In creeks draining the Sapelo salt marshes, the dry weight of organic detritus particles ranged from 5 mg (at mid-flood tide) to 20 mg (at mid-ebb tide) per liter. Approximately 90-99 percent total seston was detritus, of which over 90 percent originated from the Spartina

grass. Size distribution by weight was as follows: 1 percent coarse detritus (defined as that retained by a No. 6 net - 74 meshes per inch; 0.239mm per aperture); 4 percent fine detritus (defined as that strained by a No. 25 net - 200 meshes per inch; 0.064mm per aperture); 95 percent nanno detritus (defined as smallest particles that pass nets Nos. 6 and 25, but filtered by a membrane filter of 0.45 micron porosity). Calculations based on measurements taken through the tidal cycle in the autumn and winter of 1964 revealed an estimated net export of 186 kg and 31 kg (averages of 3 measurements) of organic matter for spring and neap tides, respectively, from the 10-25 hectare marsh area in one tidal cycle. Oxygen consumption (BOD) per gram is more than three times as great in nanno detritus as compared with coarse detritus, indicating increasing microbial activity with age. The small suspended particles are 70-80 percent ash, but the organic portion is rich in protein, up to 24 percent on an ash-free basis as compared with 10 percent in living grass and only 6 percent in the dead grass as it enters the water. Thus, the bacteria-rich detritus may be a better food source for the detritus consumers of the salt marsh-estuaries than the Spartina tissue that forms the original base for most of the particulate matter, provided the digestive tracts of detritus-feeding animals are adapted to handle large amount of undigestible mud and other ash components. Semi-qualitative estimations of stomach contents of marsh, estuarine, and coastal animals revealed the frequent occurrence (up to 50 percent of total stomach content) of organic detritus (mostly of Spartina origin); to what extent detritus present in the digestive tract is assimilated remains to be determined. The role of organic detritus as a major source of food for consumer species is reviewed and its ecological significance discussed. (A.A.)

Keywords: detritus, Spartina alterniflora, salt marsh, estuaries, Georgia

III-B-3

Odum, E.P., and A.A. de la Cruz. 1967. Particulate organic detritus in a Georgia salt marsh-estuarine ecosystem. Pages 383-388 in G.H. Lauff, ed., Estuaries. American Association for the Advancement of Science, Washington, D.C.

Estuaries in Georgia dominated by Spartina alterniflora marshes have organic detritus as the chief link between primary and secondary productivity, since only a small portion of the net production of the marsh grass is grazed while it is living. Seven aspects of detritus are being studied at the University of Georgia Marine Institute at Sapelo Island: 1) the seasonal picture of the standing crop of detritus in water; 2) size distribution and composition of detritus particles; 3) tidal transport of detritus in and out of a 10-hectare marsh area drained by a single small creek; 4) origin of the particles; 5) decomposition of marsh grass in nylon litter bags; 6) nutritive values of different age and size components; and 7) metabolism of detritus particles.

In creeks draining Sapelo marshes, organic detritus ranges from 2 mg/l at mid-flood tide to 20 mg/l at mid-ebb tide, and makes up about 90-99 percent of the total seston. The small suspended particles are 70-80 percent ash; but the organic portion is rich in protein, containing up to 24 percent on an ash-free basis as compared with 10 percent in living grass and only 6 percent in dead grass as it enters the water. Oxygen consumption (BOD) per gram is more than five times as great in "nanno detritus" (that which passes through a No. 25 net-200 meshes per inch; 0.064mm per aperture) as compared with coarse detritus (that retained by a No. 6 net-74 meshes per inch; 0.239mm per aperture), indicating increasing microbial activity with age. The nanno fraction comprises 95 percent of the total particulate organic matter. Thus, the bacteria-rich detritus is nutritionally a better food source for animals than is the Spartina tissue that forms the original base for most of the particulate matter. (Author's summary)

Keywords: productivity, detritus, Spartina alterniflora, estuaries, Georgia

III-B-4

Heald, E.J. 1971. The production of organic detritus in a South Florida estuary. University of Miami Sea Grant Technical Bulletin No. 6. 110 pp.

The mechanisms and pathways by which dead plant material is incorporated into the aquatic system, thereby constituting an important energy source, are delineated and quantified. Estimations of the annual production of dead material by red mangrove, sawgrass, and blackrush were made. The mechanisms by which such material enters the detrital pool, the rate at which this proceeds, determination of the fluctuations in the quantity, nature and origin of the detrital load were ascertained along with the potential nutrient value of dead material, if consumed at any specific stage of decomposition. (A.A.)

Keywords: detritus, estuaries, Florida

III-B-5

Odum, W.E., and E.J. Heald. 1974. Mangrove forests and aquatic productivity. Pages 129-136 in A.D. Hasler, ed., Coupling of land and water systems. Springer-Verlag, Berlin.

The importance of terrestrial primary production as a source of energy in aquatic ecosystems is outlined. Detritus particles originating from trees, shrubs, sedges, and grasslands in the watershed are the primary energy source. Mangrove swamps are used as an example. The article discusses: 1) mangrove swamps and coastal waters, including an interaction hypothesis and evidence from a Florida mangrove swamp; 2) production and losses of organic matter, including foliage production,

decomposition of mangrove leaves, and the export of mangrove leaf material; 3) qualifications to the hypothesis, including magnitude and total production of the mangrove ecosystem; and 4) location of consumer communities. (J.B.)

Keywords: mangrove, primary productivity, detritus, Florida

III-B-6

Blum, J.L. 1968. Salt marsh Spartinas and associated algae. Ecological Monographs 38:199-221.

An investigation of the algae of the high salt marsh, particularly their microdistribution and ecology, and the relationships between algae and the graminoid vegetation was conducted in Barnstable marsh on Cape Cod between 1959 and 1965.

The ontogeny of the habitats of principal algal communities of the high salt marsh is outlined; in particular, the steps by which the Spartina patens community becomes prostrate and converted to a horizontal, well-aerated mat-like structure are described. Spartina patens exhibits a series of adaptations which permit the construction and maintenance of this mat: temporary vane action of the leaf blade, subsequent sclerification of much of the blade and subtending internode, gravity, wind, tidal submergence, "prop" leaves, leaning of the plant and a culm base which bends easily but which exhibits considerable tensile strength, are all involved in this process. Many of the features of this mat are also found in dense stands of Distichlis spicata. Light conditions of certain algal habitats become marginal as the salt marsh graminoids grow during summer months. Light values at the soil surface under mature stands of S. patens and D. spicata are probably limiting or marginal at all times. On the Barnstable marsh, soil under mature S. patens is slower to warm in spring than under S. alterniflora; particularly is this true when S. alterniflora of creekbanks is considered.

Relative humidity values at the level of surface grass on the dead S. patens mat are commonly low and probably prevent algal growth here. Humidity values at deeper levels with the mat of dead grass are more favorable, but light becomes limiting here and algal growth is usually conspicuous only where the mat is relatively thin. The primary and most successful algal colonist on the moist portion of the dead S. patens is a species of Calothrix. Widespread algal colonization of the S. patens mat would clearly contribute materially to the rapid destruction of the mat. Due to the levels of humidity and light that are achieved through the presence of the S. patens mat in mature stands, the growth of algae is effectively suppressed. In contrast to the sparse or non-existent algal colonization of mature S. patens and mature Distichlis spicata, a continuous and nearly ubiquitous algal layer is present under high marsh (stunted) S. alterniflora. Partly

as a result of this algal growth, dead S. alterniflora commonly decays much more rapidly than S. patens.

The principal algal communities of the high marsh are enumerated and described. Different hypotheses as to the function and significance of the S. patens mat are considered. There is evidence that it serves to conserve detritus within the S. patens community. The possible function of the mat as a trap for allochthonous nutrients is discussed. (Author's summary and B.W.)

Keywords: high salt marsh, Spartina, algae, nutrients, Cape Cod

C. Decomposition and Nutritive Value Changes

III-C-1

Burkholder, P.R., and A.H. Bornside. 1957. Decomposition of marsh grass by aerobic marine bacteria. Bulletin of the Torrey Botanical Club 84:366-383.

The article describes the methodologies used in analyzing decomposition of Spartina alterniflora on Sapelo Island, Georgia, during the period November 28, 1955-September 19, 1956.

Many organisms isolated from marsh muds were able to grow well on seawater extracts of Spartina grass, which is abundant in the habitat of the bacteria. The amino acid requirement of these isolates is probably supplied chiefly by marsh grass, mud organisms, and plankton crops in the natural environment. The large numbers of bacteria present in the marine muds of the Georgia sea island region have been found to participate actively in the decomposition of Spartina, both in the field and in the laboratory. Quantitative data provided an estimate that eleven percent of the annual crop of marsh grass may be rapidly converted to bacteria (dry weight basis). Marsh mud extracts failed to serve as an enrichment medium for aerobic heterotrophic bacteria unless supplemented with organic materials. (L.H.)

Keywords: Spartina, bacteria, marsh grass, Georgia

III-C-2

Meyers, S.P. 1974. Contribution of fungi to biodegradation of Spartina and other brackish marshland vegetation. Louisiana State University, Baton Rouge, Department of Food Science (reprint).

Transformation of marsh grass, Spartina alterniflora, to detritus is an initial energy transfer step in the coastal Louisiana estuarine ecosystem.

Spartina is systematically attacked by a selective mycota throughout its development and decomposition. Fungi include, among others, species of Fusarium and Cephalosporium as well as representatives of the marine taxa Lulworthia and Leptosphaeria. Molds colonizing external plant surfaces differ from those isolated within the culm. Fungal attack is correlated with seasonal development and subsequent decomposition of the plant. A large yeast biomass, notably sporogenous taxa Pichia spartinae and Kluyveromyces drosophilorum, is prevalent in the oxidized portions of the Spartina rhizosphere and within the peripheral tissue and intercellular spaces of the culm. These species, with strong B-glucosidase activity, reach maximal populations during dieback of Spartina. A mutualistic yeast/mold association in turnover of plant substrates is suggested. (A.A.)

Keywords: detritus, Spartina, biodegradation, fungi

III-C-3

May, M.S. 1974. Probable agents for the formation of detritus from the halophyte, Spartina alterniflora. Pages 429-440 in R.J. Reimold and W.H. Queen, eds., Ecology of halophytes. Academic Press, New York.

Microbial decomposition has been generally accepted as the major cause of the degradation of dead plants to detritus, and recently, several invertebrates have been shown to play a role. The purpose of this work was to investigate probable agents of detritus formation from smooth cordgrass (Spartina alterniflora), the dominant grass of the intertidal marshes of Georgia. The study found that microbial decomposition of dead Spartina does occur and is probably due to fungi and that macro-invertebrates, especially Cleantis planicauda, are major degraders of dead Spartina to detritus. (J.B.)

Keywords: detritus, Spartina alterniflora, decomposition, intertidal marshes

III-C-4

Burkholder, P.R. 1959. Some microbiological aspects of marine productivity in shallow waters. Pages 70-75 in Proceedings of the salt marsh conference, Sapelo Island, Georgia. University of Georgia, Athens.

Salt marshes of the eastern coast of North America and the Caribbean vary greatly in kind of substrate and floristic composition. Dominant plants with submerged roots and rhizomes and aerial shoots frequently occur in the tidal areas of these marshes. Spartina is abundant in the temperate regions, and species of mangrove are characteristic of tropical areas. Submerged plants such as eel grass, manatee grass and turtle grass are abundant primary producers in their respective areas. Oftentimes associated with shallow water communities of mangrove and turtle grass, such as occur in Puerto Rico, are the coral reefs,

which are unique associations of symbiotic coelenterates and photosynthetic dinoflagellates. The mud surface in different latitudes appears generally to support growth of diatoms, blue-green algae and other primary producers. In all of these areas periodic blooms of planktonic diatoms and dinoflagellates are at various times important to the total productivity. Studies on the crops and residues of typical communities indicate that microbial decomposition plays an important role in the turnover of the primary organic matter for consumption by herbivores and carnivores. Bacteria constitute an active group of small plant converters which aid in formation of detritus, much of which then is available for the micro- and macro-fauna of marshes and nearby marine areas.

The amount of standing crop of plankton or of flowering plants may provide a rough indication of the productivity. Thus, suspended dry materials in blooms, measured by millipore filter technique, in Long Island Sound, at Sapelo, Ga., and in the Bahia Fosforescente, Puerto Rico, have given the following values in milligrams per liter: 16.8, 22 to 159, and 14.4. Great variations occur, and this approach only indicates what is present at any given time, not the overall production. Other methods (e.g., measurements of carbon fixation with C-14, oxygen production in dark and light bottles, etc.), provide better indices to primary productivity. A discussion is included at the end of the paper. (Author's introduction-modified).

Keywords: marine productivity, Spartina, salt marshes, U.S. east coast, Puerto Rico

III-C-5

Meyers, S.P., M.L. Nicholson, J.S. Rhee, P.C. Miles, and D.G. Ahearn. 1970. Mycological studies in Barataria Bay, Louisiana, and biodegradation of oyster grass, Spartina alterniflora. Louisiana State University, Coastal Studies Bulletin No. 5, Special Sea Grant Issue, pp. 111-124.

This paper investigates biodegradative processes in the Spartina ecosystem, with particular emphasis on the ecological role of yeasts and filamentous fungi. The ability of the marine-occurring yeasts to assimilate nonprotein nitrogenous substrates, and the capacity of certain taxa to produce extracellular proteolytic enzymes, is being examined. Particular attention is directed to utilization of amine and amine-related compounds of considerable biochemical and economic significance in fisheries technology and in marine biology in general. In view of their role as detrital feeders, certain portions of the nematode biota also are being considered.

Attention was given to higher sections of the marshland supporting dense Spartina growth, and particularly to the area of the plant system commonly termed a "rhizosphere" environment. In terrestrial habitats, the rhizosphere is that portion of the plant/soil zone characterized

by intense microbial activity resulting ultimately in establishment of a distinctive rhizosphere microflora. The microbial equilibrium of the soil is affected by the growing plant. Superimposed on the root effect are the multitude of associative and antagonistic reactions among the microorganisms themselves.

Author-related mycological studies in the South Florida and Everglades region, the North Sea, and Lake Champlain have suggested that yeast populations in these locales may be interpreted from aspects of both "standing crop" and "bloom" development. Investigations reported in this paper on yeasts of the Louisiana marshland support these observations. It is hoped that analysis of microbial successional patterns will provide information on fluctuations in microbial populations associated with plant growth, ability of yeasts to compete with bacteria for available nutrients, and the nature of yeast physiological ecology. The predominant marshland yeast population is cellobiose-utilizing and must be able to compete with the bacteria present for this carbohydrate. In view of the inability of yeasts to degrade cellulose, their role in the Spartina biodegradation probably involves mainly utilization of products resulting from a primary attack on the plant matter by other organisms. Further development of studies on the total cellulolytic biomass (both bacteria and fungi) in the Spartina habitat will provide essential information on the rate of turnover of plant substrate and release of nutrients for microbial activities. The complexity of microbial relationships in degradation of submerged cellulosic substrates will require detailed investigation of the biology of the organisms involved. (G.S.)

Keywords: mycology, biodegradation, oyster grass, Spartina alterniflora, coastal marshes, Louisiana

III-C-6

Cowley, G.T. 1973. Variations in soil fungus populations in a South Carolina salt marsh. Pages 441-454 in L.H. Stevenson and R.R. Colwell, eds., Estuarine microbial ecology. University of South Carolina Press, Columbia.

Since the publication of research during the 1930s on the fungi of the Dovey salt marsh soils, little new data have appeared in the literature which would contribute to the understanding of salt marsh soil fungus populations. The work done to date has concentrated primarily on taxonomy of isolates rather than population structure. This study was an attempt to assess variations in soil fungus populations and to prepare the groundwork for further studies on the evaluation of the effects of environmental variables. The role of saprophytic fungi in salt marsh soil environments was considered. Although many salt marshes are available for study in South Carolina, the Hobcaw Barony salt marsh near Georgetown, South Carolina, was selected because it is apparently less influenced by domestic and

industrial activities than most others in the state. In addition, its associated estuary system is under intensive investigation by a number of biologists.

Total populations of soil fungi per gram fresh weight and dry weight of soil were highest in the Spartina debris zone during November and March sampling periods. Although it was not measured, the dark color of the soil in this zone suggested it contained a higher organic matter content than surrounding soils. November tall Spartina and dwarf Spartina populations, per gram of fresh soil, were much lower than those in the Spartina debris and Juncus zones. However, tall Spartina and dwarf Spartina zone populations per gram dry soil were near those of the Juncus zone. In March, populations per gram dry soil in the wet end of the marsh were much lower than either the Spartina debris or Juncus zones. Salicornia zone populations per gram fresh and dry soil were lowest during both sample periods. (G.S.)

Keywords: soil fungus, salt marshes, marsh grasses, South Carolina

III-C-7

Newell, S.Y. 1973. Succession and role of fungi in the degradation of red mangrove seedlings. Pages 467-480 in L.H. Stevenson and R.R. Colwell eds., Estuarine microbial ecology. University of South Carolina Press, Columbia.

The paper deals with the study of the fungal populations involved in the energy turnover of the seedling segment of Rhizophora production. Fell and Master showed that the red mangrove, Rhizophora mangle, is an extremely important contributor to the productivity of south Florida estuarine waters; a constant flow of energy passes from the red mangrove plants to the estuarine ecosystem via the vast amounts of organic matter cast off by the plants. Microbial mediators convert this detritus into nutrient matter utilizable by small macroorganisms at the base of the food web. In the case of Rhizophora leaf and twig materials, this conversion is well documented. The production of the viviparous seedlings and the contribution of this production to the estuarine ecosystem as nutritive biomass have been ignored.

However, by combining previous data for mean density of mature Rhizophora trees per unit area, and for production of seedlings per adult tree per producing season with data on average seedlings mass (6.5g) gathered during the present study, a figure for seedling biomass production per unit area (7.9 metric ton/acre/summer season) is obtained. This figure is twice that for leaf and twig debris (3.6 metric ton/acre/yr). The great majority of the seedlings fail to take root, and the number of seedlings set adrift in southeastern Florida coastal waters has been estimated to run into the millions. These estimates suggest that

cast-off mangrove seedlings form a significant contribution to the estuarine productivity of south Florida.

It was found that the role of fungi in the degradation of red mangrove seedlings appeared to be as invaders of the protective external tissues. In injured seedlings, bacteria and protozoa entered the pith tissues via the wound and rotted them. Both injured and uninjured sets of seedlings exhibited similar fungal successions, involving a procession from Hyphomycetes to Sphaeropsidales, Ascomycetes, and Hyphomycetes. It seemed that the fungi might take the place of mechanical injury as the agents which would cause uninjured seedlings to be susceptible to bacterial-protozoan destruction of the starch-laden pith tissues. In any case, a unique community of fungi appeared to play an important part, in conjunction with bacteria, in the first stages of conversion of seedling biomass to microbial biomass, the first step in the passage of seedling energy into the estuarine food web. (Author's summary and G.S.)

Keywords: plant succession, fungi, red mangrove, detritus, estuarine ecosystem, Florida

III-C-8

Fell, J.W., and I.M. Master. 1973. Fungi associated with the degradation of mangrove (Rhizophora mangle L.) leaves in South Florida. Pages 455-465 in L.H. Stevenson and R.R. Colwell, eds., Estuarine microbial ecology. University of South Carolina Press, Columbia.

Odum and Heald observed that during the degradation of the mangrove leaf there is a significant increase in the relative amount of protein and conjectured that the fungal protein might be an important food source for detrital consumers. As a continuation of these observations, the authors initiated a program to ascertain the role of fungi in this degradation system. In the initial phases of the study, they examined the decaying leaves to determine which fungi were present during the various stages of the process. The paper lists those fungi that were identified, discusses observations on the sequences of infestations, and generally characterizes the leaf fungal community.

The authors conclude that it appears that a wide range of fungal genera, including Phycomycetes, Deuteromycetes, and Ascomycetes, are associated with the degradation of the mangrove leaves. Considerable research is required to determine the specific role of these organisms in the food web, although it has been postulated that they are important in the production of protein as a food source for small fishes and invertebrates. It is extremely important to understand the dynamics of this ecosystem and the effects of alterations in environmental conditions. The mangroves of south Florida are being subjected to a variety of abnormal conditions, including effluents from domestic and industrial sources; therefore, it is necessary to know how these

alterations will affect the entire food web. More important (the authors contend) is the value of the mangrove system to the marine environment as the mangroves are rapidly disappearing as a result of urbanization. (G.S.)

Keywords: fungi, mangrove, detritus, Florida

III-C-9

De la Cruz, A.A., and B.C. Gabriel. 1973. Caloric, elemental, and nutritive value changes in decomposing Juncus roemerianus leaves. Association of Southeastern Biologists Bulletin 20:47. (Abstr.)

In situ decomposition of Juncus roemerianus (Juncaceae) leaves determined by litterbag method was 0.40/yr. Caloric, elemental, and proximate nutritive analyses of leaves at various stages of life and decay (namely: young, mature, standing dead, partially decayed, decomposed fragments, and particulate detritus) showed the following: (a) increase in caloric content (4630 to 4911 gcal/ash-free g); (b) decrease in carbon (49.75 to 6.38 percent), nitrogen (1.09 to 0.57 percent), phosphorus (0.22 to 0.17 percent); (c) decrease in crude fiber (37 to 9 percent), carbohydrate (47 to 11 percent), protein (8 to 4 percent) and fats (2.4 to 0.85 percent). Particulate detritus recovered from litterbags decomposed in incubation flasks at the rate of 0.50/36 days. At intervals of 0, 5, 13, 25, and 36 days, analyses of detritus showed the following: (a) decrease in organic content (67 to 32 percent) and carbon (5.6 to 3.2 percent); (b) increase in nitrogen (0.44 to 1.21 percent) and respiration rates (0.36 to 3.63 ppm O_2 hr⁻¹ ash-free g⁻¹). The increase in N and consequently protein is attributed to conversion of plant-detritus tissue to microbial protoplasm, as evidenced by increased respiration rates. (A.A.)

Keywords: detritus, Juncus roemerianus, decomposition

III-C-10

De la Cruz, A.A. 1975. Proximate nutritive value changes during decomposition of salt marsh plants. Hydrobiologia 47:475-480.

Recognition of salt marsh plant detritus as a nutritious source of food for estuarine consumers prompted investigation of in situ decomposition and proximate nutritive values of three plants and their detritus; namely: Spartina cynosuroides and Distichlis spicata (Gram.) and Scirpus americanus (Cyperaceae) growing abundantly in Mississippi tidal marshes. During decomposition to particulate detritus, these plants retain 60-70 percent organic content, and the caloric value either remains the same or increases slightly. Crude fiber, carbo-

hydrate, and fat contents decline, but protein shows a 96-300 percent increase from dead plants to the particulate detritus stage. (J.B.)

Keywords: detritus, nutritive values, salt marsh plants

III-C-11

De la Cruz, A.A., and W.E. Poe. 1975. Amino acids in salt marsh detritus. *Limnology and Oceanography* 20:124-127.

Amino acids declined by greater than 50 percent at the death of marsh plants, but increased again almost to the level of the living plant during in situ decomposition. A decline in the ratio of amino acid to crude protein in spite of increases in both implies that there are nitrogen sources in the marsh other than the amino acids and ammonia in the plants. (J.B.)

Keywords: amino acids, salt marsh, detritus

III-C-12

Gosselink, J.G., and C.J. Kirby. 1974. Decomposition of salt marsh grass, Spartina alterniflora Loisel. *Limnology and Oceanography* 19:825-832.

Dead standing Spartina alterniflora stems and leaves were obtained from the Barataria Bay area of coastal Louisiana in November. The S. alterniflora stems and leaves were ground, dried, separated into four size fractions from 67- to 218-micron average diameter, and incubated in the dark at 30°C in inoculated artificial seawater. Particulate nitrogen, oxidizable carbon, dry weight, and metabolic rate were measured for 30 days. The conversion efficiency of substrate to microbial biomass ranged from 28 percent to over 60 percent, decreasing as substrate particle size increased. (B.W.)

Keywords: Spartina, decomposition, biomass, Louisiana

D. Suspended and Transported Nutrients

III-D-1

Happ, G. 1974. The distribution and seasonal concentration of organic carbon in a Louisiana estuary. M.S. Thesis, Louisiana State University, Baton Rouge. 36 pp.

Organic carbon content is a direct measure of the amount of detritus present in an area. There have been numerous studies on the carbon

content of the ocean, but little to date in estuarine areas. Since primary production alone does not account for the amount of carbon contained in the open sea, it may be assumed that the Gulf of Mexico receives some of its carbon supply from fringing estuaries in the form of detritus. These estuaries are supported by a watershed of 919,000 acres of marsh and open water and more than 50,000 acres of freshwater swamp.

The concentration and distribution of detritus in the coastal waters of the Barataria hydrological unit were measured using organic carbon analysis. Dissolved organic carbon (DOC), total organic carbon (TOC), and chlorophyll a (Chl a) were measured monthly from November 1972 to November 1973 at stations from the upper, middle, and lower areas of Caminada and Barataria bays and in the Gulf of Mexico.

DOC was highest in the marsh areas, averaging 6.7mg/l, and decreased toward the middle and lower bay where the average DOCs were 5.7mg/l and 4.7mg/l, respectively. The average DOC for Gulf water was 2.6mg/l. Bay levels were highest in winter and lowest in the spring, while off-shore concentrations were lowest in the winter and increased toward fall. TOC values closely followed those for DOC. There were three TOC peaks: in winter, early spring, and late summer. The winter peak corresponded to high DOC. The spring and summer peaks probably represent particulate organic carbon (POC). Chl a was highest in the bay areas and had seasonal peaks in late January and July.

Low temperature and north and easterly winds of 6-10 mph were positively correlated with DOC. The winds could have stirred up the bottom sediments, causing release of interstitial DOC into the water column. Organic carbon concentration in the bays is controlled by seasonal phenomena related to organic production and release, by water level, by influx of Gulf water, and possibly by influx of river water.

Input of primary production to an estuary originates from three sources: macrophytes (marsh grass, sea grass, mangrove, and macroalgae); benthic microalgae (benthic and epibenthic diatoms, dinoflagellates, and filamentous algae); and phytoplankton. Although each estuary has its own characteristic proportions of these three inputs, macrophytes tend to be most important in shallow marsh-fringed estuaries and phytoplankton least important.

Some of the primary producers in the region studied were Spartina alterniflora (the most abundant), Distichlis spicata, Juncus roemerianus, Salicornia virginica, and Avicennia germinans. Four genera of macrophytic algae were found regularly: Bostricha and Polysiphonia in the summer and Enteromorpha and Ectocarpus in the winter. Major epiphytic diatoms found were Amphora, Cocconeis, Melosira, Denticula, and Nitzschia. Through estimates of marsh production, with proper allowances for consumption by such fauna as copepods, shrimp, oysters, and other

filter-feeding animals, approximately 300 g C/m^2 water surface/year was estimated for export from the estuary or deposition in sediments. (G.S.)

Keywords: productivity, detritus, carbon, estuary, Louisiana

III-D-2

Allen, R.L. 1975. Aquatic primary productivity in various marsh environments in Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge. 50 pp.

Dissolved oxygen, total organic carbon, dissolved organic carbon, and chlorophyll a were measured from September 1973 to August 1974 at both natural and altered stations along a north-south transect which crossed all major marsh environments characteristic of south Louisiana.

Organic carbon was statistically related to net community production, but not to gross production, supporting the idea that marsh-bordered estuaries are detritus-based. In addition, there was a significant correlation between gross production and chlorophyll levels. Net community production, TOC, and DOC were highly related with chlorophyll.

The study area did not demonstrate a strong seasonal trend in productivity, a condition that is often evident in higher latitude temperate estuaries. Seasonal production rates tended to be erratic, largely because of the semitropical climate that prevails in southern Louisiana. Rates were found to be generally higher in the summer, with occasional phytoplankton blooms. There was a strong correlation between water temperature and productivity. (L.H.)

Keywords: primary productivity, marsh environments, Louisiana

III-D-3

Heinle, D.R., D.A. Flemer, J.F. Ustach, and R.A. Murtagh. 1975. Contributions of tidal wetlands to estuarine food chains. Maryland Water Resources Research Center, College Park, Technical Report No. 29.

The flows of detritus and nutrients from stable marshes in the upper Patuxent estuary subjected to low tidal amplitude were slight. The quality of particulate carbon flowing from the marsh to the estuary was less than 10 percent of annual production. By contrast, a portion of the marshes subjected to scouring by ice lost virtually all of its aboveground biomass to the estuary and contributed over half of the annual carbon budget to the system. (J.B.)

Keywords: productivity, detritus, algae, estuary, Maryland

III-D-4

Rhoads, D.C., K. Tenore, and M. Browne. 1975. The role of resuspended bottom mud in nutrient cycles of shallow embayments. Pages 563-582 in L.E. Cronin, ed., *Estuarine research*, Vol. 1. Academic Press, New York.

The bottom of Buzzards Bay, Massachusetts, below a depth of about 13 meters, is dominated by silt-clay sediment. Water flowing near the bottom is turbid because of resuspension of the bioturbated mud surface by tidal-current scour. The turbid-water layer extends about 3 meters above the bottom and may extend higher during spring tides. Maximum turbidity develops during mid-ebb tide. A seasonal turbidity cycle also exists. Minimum values of suspended carbon were measured in April and May when bioturbating activities of the benthos were at a minimum.

The concentration of particulate organic carbon (POC), particulate organic nitrogen (PON), and chlorophyll *a* in both surface and bottom water were measured at one station over an 11-month period. Seasonal changes in these variables in surface and bottom waters showed two maxima related to peak phytoplankton production: one in the winter (December-January) and another in the autumn (September-October). Throughout most of the year, concentration of these consumer nutrients is higher in bottom water than at the surface.

Although primary production takes place in surface water, detritus from this production sinks and is concentrated on the muddy sea floor, stimulating bacterial growth. The significance of this nutrient-rich detrital resource for benthic productivity and aquaculture is discussed. (A.A.)

Keywords: detritus, productivity, nutrient cycles, Massachusetts

III-D-5

Haines, E.B. 1976. Stable carbon isotope ratios in the biota, soils and tidal water of a Georgia salt marsh. *Estuarine and Coastal Marine Science* 4:609-616.

The stable carbon isotope composition of the biota, soils and tidal water particulate material was surveyed in a salt marsh near Sapelo Island, Georgia. Samples were taken in six intertidal zones: base creekbank, *Spartina alterniflora* low marsh, *S. alterniflora* high marsh, *Salicornia virginica* high marsh, sand flat, and high marsh mixed vegetation stands.

The marsh plants analyzed segregated into three groups with respect to their $^{13}\text{C}/^{12}\text{C}$ ratios. The grasses, including *S. alterniflora*, had $\delta^{13}\text{C}$ values of -12.3 to -13.6 ppt; the other vascular plants had values between -22.8 and -26.0 ppt, and benthic diatoms had

intermediate values of -16.2 to -17.9 ppt. Marsh soils and to some extent the invertebrate fauna reflected the carbon isotope composition of the major primary producer species in the various zones.

Five samples of the particulate organic carbon (POC) in marsh tidal water showed $\delta^{13}\text{C}$ values of -19.8 to -22.8 ppt. These values fell within the range of $\delta^{13}\text{C}$ found for offshore POC, most of which is presumed to originate from phytoplankton photosynthesis. This result requires a reexamination of the assumption that the bulk of detrital carbon in Georgia estuaries is derived from S. alterniflora production.

A general assumption about the detrital carbon in estuaries has been that most of this carbon is derived from the production of macrophytes. However, Odum and de la Cruz (1967) reported that 95 percent of the particulate carbon in estuarine waters near Sapelo Island was in the nanno fraction and consisted of amorphous particles with no recognizable S. alterniflora fragments. There is also recent evidence that salt marshes may exhibit a net consumption rather than a net export of carbon. The carbon isotope composition of estuarine POC found in this study further opens to question the source of this carbon. Either a significant fraction of the estuarine carbon is derived from sources other than S. alterniflora such as phytoplankton production or C-3 plant material, or S. alterniflora carbon present in the nanno fraction of the POC has been fractionated to yield a carbon isotope composition very different from that of the live plant. (J.B.)

Keywords: marsh biota, tidal marshes, carbon, vascular plants, marsh ecosystems, productivity, detritus, Georgia

III-D-6

Schultz, D.M. and J.G. Quinn. 1971. Studies on the formation of particulate matter from Spartina alterniflora in a salt marsh in Narragansett Bay, Rhode Island. Page 199 in D.S. Gorsline, ed., Second national coastal and shallow water research conference; abstract vol. University of Southern California, Los Angeles. (Abstr.)

Recent studies have suggested that salt marshes are a major source of particulate matter found in estuarine waters. This material, which is thought to be derived largely from marsh grasses, is a source of energy for deposit/filter feeders. There is a net flux of particulate carbon flowing out of the salt marsh, which is considered to be one of the most productive areas in the world.

A relatively unpolluted salt marsh (Bissel Cove) on the west shore of Narragansett Bay was selected. Particulate matter was collected monthly on both ebb and flood tide, and analyzed for fatty acids. The weight of particulate matter was determined on a dry weight basis and milligrams of particulate matter per liter water and microns of

fatty acid per milligrams of particulate matter (micron/milligram) were recorded. On the micron/milligram basis, virtually no distinction could be made between ebb and flood tides, and the fatty acid composition was nearly the same. Values ranged from 2.5-7 microns fatty acid/mg particulate matter.

The fatty acid composition of the major marsh grass Spartina alterniflora has also been determined monthly. The microns fatty acid per milligrams of dry weight grass was recorded. In the dead grass, which is thought to be the source of the major fraction of the particulate matter, the micron/milligram values were very low: 0.8-1.3.

A laboratory study on the breakdown of S. alterniflora was made under aerobic and anaerobic conditions, and the particulate matter was analyzed weekly on the aerobic, and after 18 weeks on the anaerobic. On a micron/milligram basis, the greatest change occurred within the first eight weeks, starting at 1.2 microns/milligram grass. After one week the particulate matter was 9.9 microns/milligram, then dropped in value, leveling off at about 3.2 microns/milligram after six weeks. The anaerobic system had a value of 7.6 microns of fatty acid/mg particulate matter after 18 weeks. The study was repeated under field conditions. (A.A.)

Keywords: Spartina, salt marshes, food chain, Rhode Island

III-D-7

Odum, E.P. 1968. A research challenge: evaluating the productivity of coastal and estuarine water. Pages 63-64 in Proceedings of the Second Sea Grant Conference, University of Rhode Island.

These are brief remarks by one of America's foremost experts on coastal marsh productivity. Odum points out that "most fertile zones in coastal areas capable of supporting expanded fisheries result either from the 'upwelling' of nutrients from deep water or from 'outwelling' of nutrients and organic detritus from shallow-water nutrient traps such as reefs, banks, seaweed or sea grass beds, algal mats and salt marshes. The importance of the latter as primary production pumps that 'feed' large areas of adjacent waters has only been recently recognized, and many of these production foci are needlessly endangered by pollution, dredging and filling." Apparently, large rivers do not have so great a local effect on the productivity of estuaries and coastal waters as was once assumed. The most important discovery the author and his co-workers have made in their 15-year study of production dynamics on the Georgia coast is that the high fertility of this region is self-produced within the salt marsh estuary, and is not due to nutrients washed down the rivers. They could find no statistical difference between carbon-14 on other measures of primary production at the river mouths as compared with localities at a distance from a river mouth. Carbon-14 productivity of coastal

waters near and far from large river mouths are compared. If anything, areas right at the river mouth are low, probably due to the silt load. Odum explains the unusually high productivity of Georgia offshore water as follows: "so much organic matter is produced in the extensive salt marshes and combined with so much sediment that much of the contained nutrients can not be utilized within the estuary because of low light penetration. When these nutrients reach the clearer waters offshore they support a year-round plankton bloom (and presumably, also a fishery not yet exploited)." (J.B.)

Keywords: productivity, estuaries, coastal marsh, nutrient outwelling, Georgia

III-D-8

Ho, C.L., and B.B. Barrett. 1975. Distribution of nutrients in Louisiana's coastal waters influenced by the Mississippi River. Louisiana Wildlife and Fisheries Commission Technical Bulletin 17. 39 pp.

The objectives of this investigation were: (1) to determine the concentration and distribution of the major available nutrients emptied into the Gulf of Mexico by the Mississippi River at various discharge stages; (2) to assess the importance of nutrient supply sources other than the Mississippi River, especially in estuarine systems; and (3) to provide basic information for future assessment of the Mississippi River's impact on fisheries production in the Gulf of Mexico and estuarine systems influenced by the river.

It was found that during heavy flooding by the Mississippi River throughout Louisiana's coastal areas large amounts of freshwater were discharged into these areas. Salinities were diluted and large amounts of land-derived inorganic nutrients and organic nitrogen were added to the coastal waters. Differences in chemical composition indicated that the influence of the Mississippi River on Barataria and Caminada bays was limited to the lower region of these bays during the period of study. Sources of freshwater and associated nutrients introduced into the bays were largely runoff waters from the upper marshes via connecting waterways, bayous and drainage canals.

When the Mississippi River discharge was lowest, the entire nearshore waters were dominated by nutrient-depleted seawater. Inorganic nutrients and organic nitrogen in the estuaries and the adjacent nearshore waters were much higher than at the river mouth during that time, which indicates the importance of the marshlands as a source of inorganic nutrients and organic matter to the estuaries and adjacent nearshore waters. However, the estimated quantity of selected chemical components discharged by the Mississippi River from January through July 1973 was 28.4 billion pounds. Such vast amounts of inorganic

nutrients and organic matter undoubtedly are the primary factors that result in Louisiana's high fishery production. (H.D.)

Keywords: nutrients, estuarine systems, fisheries, river discharges, coastal marsh, Louisiana

III-D-9

Haines, E.B. 1975. Nutrient inputs to the coastal zone: the Georgia and South Carolina shelf. Pages 303-324 in L.E. Cronin, ed., *Estuarine research*, Vol. 1. Academic Press, New York.

The concept of "outwelling" of nutrients from salt-marsh estuaries to coastal waters as proposed by E.P. Odum is evaluated for the Georgia and South Carolina shelf. The distribution of inorganic nutrients, particulate organic carbon, and chlorophyll a was determined in shelf waters between Charleston, South Carolina, and Fernandina Beach, Florida. Nearshore, lower salinity waters were enriched in phosphate, organic carbon, and chlorophyll a, but contained little nitrate or ammonia. A budget of the nitrogen influx from terrestrial discharge, intrusion of nutrient-rich deep water at the edge of the shelf, and precipitation was calculated for the shelf area studied. The annual nitrogen input was less than five percent of the calculated yearly uptake of nitrogen by primary producers on the shelf, suggesting that regeneration is the most important factor in maintaining high rates of production in the coastal waters of Georgia and South Carolina. (A.A.)

Keywords: nutrient outwelling, salt marsh, estuaries, Georgia, South Carolina

III-D-10

Ketchum, B.H. 1967. Phytoplankton nutrients in estuaries. Pages 329-335 in G.H. Lauff, ed., *Estuaries*. American Association for the Advancement of Science, Washington, D.C.

This paper provides a brief review of the comparative effectiveness of various sources of enrichment in estuaries. It also suggests how it may be possible to identify different sources of water and evaluates the contribution of each source to the fertility of the estuary.

Fertilization of estuaries is achieved in three main ways: (1) river waters leach plant nutrients from the soil and carry a constant supply through the estuary; (2) pollution, either locally within the estuary or indirectly through the river, may enrich the waters and increase productivity; and (3) the subsurface countercurrent, which is a unique characteristic of many estuarine circulations, may enrich the estuary when the sea water is drawn from below the euphotic zone where nutrient

concentrations are higher than at the surface. In each estuary, these three enrichment processes proceed simultaneously.

Oceanwide, the annual contribution of nutrients by all of the rivers of the world appears to provide for only a small part of the total marine productivity. Data are provided showing the nutrient budget of the oceans regarding nitrogen, phosphorus, and silicon, and the use of these elements by phytoplankton. The oceans appear to be nearly in steady state with regard to the contributions of these elements by the rivers. Great as the local enrichment of estuaries by the river may be, it appears that the oceanographer need not invoke this supply to maintain productivity of the oceans.

In considering pollution as an enrichment source, it was determined that phosphorus can be used as an index of excess pollution in estuarine waters. Three bays off Long Island, New York, were used for experimentation and data gathering. It was found that the concentration of inorganic phosphorus was several times greater than the usual content of sea water in this area. The phytoplankton count reflected a true bloom, far exceeding the populations found in normal unpolluted estuarine waters. "Weed" species grow prolifically in this estuary. They are not, however, good food for many of the normal populations, but their growth excludes the normal estuarine phytoplankton species. While fertilization may increase the production of species of value to mankind, uncontrolled pollution, even though it may increase the total productivity of phytoplankton, may destroy the natural resources of an estuary.

Circulation in estuaries is frequently characterized by a two-layered flow with the surface layers diluted by river water escaping seaward and the salt water entering near the bottom. The estuary may be fertilized by this seawater countercurrent, since, in many cases, the sea water is drawn from depths below the euphotic zone in the ocean where the concentration of nutrients has not been depleted by the growth of phytoplankton. Organisms grown in the surface layers of the estuary may sink to countercurrent depths where decomposition releases the nutrients, which will then be returned again for reuse within the estuary. Nutrients can thus become trapped within the estuary and build up unusually high concentrations. (H.D.)

Keywords: phytoplankton, nutrients, estuaries

III-D-11

Patrick, R. 1967. Diatom communities in estuaries. Pages 311-315 in G.H. Lauff, ed., *Estuaries*. American Association for the Advancement of Science, Washington, D.C.

This paper explores the ecological factors affecting the occurrence of diatoms and the structure of diatom communities. The types of diatoms that compose estuary communities are usually benthic and neritic species,

although some truly oceanic plankton species may be brought in by tidal action or wind.

The nutrient level of the water has a great deal to do with the number of diatoms an estuary will support. Compared with the open sea, estuaries are usually fairly high in nutrients. Diatom population varies with the amount of nutrients provided.

The algae are one of the most important groups at the base of the food chain or web, and so the more diversified the community of algae is, the more useful it will be to a greater variety of organisms that prey upon it. The distribution of the biomass of algae into a few species jeopardizes its usefulness as food.

Not only the biomass, but also the diversity pattern and the kinds of species, must be considered to understand a community or to relate it to the flow of energy in the food chain. It is conceivable that a much smaller biomass of species that provides desirable sources of food might be more valuable to the food chain than a larger biomass fixed in undesirable food species. The total biomass may be correlated with nutrient level of the water, but its importance in the food chain is greatly influenced by the kinds of species that compose it. (H.D.)

Keywords: diatoms, estuaries, nutrient levels, biomass

III-D-12

Hackney, C.T. 1977. Energy flux in a tidal creek draining an irregularly flooded Juncus marsh. Ph.D. Thesis. Mississippi State University. 83 pp.

The flux of suspended organic detritus, floating debris and animal biomass from a Mississippi tidal creek was studied during ten diurnal tidal periods (24 hour) and three semi-diurnal tidal periods (12 hour) between May 1975 and April 1976. There was a net export of floating debris (3.1 kg) and animals (0.49 kg), but a net import of suspended particulate detritus (38.5 kg) during the 13 tidal periods studied.

The concentration of suspended particulate organic detritus was predictable during ebb tide and was dependent primarily on tidal height, season, physical characteristics of the water (e.g., temperature, salinity and dissolved oxygen) and the concentration of the fauna within the creek. The concentration of particulate organic detritus was not predictable during flood tide.

Thirty species of fishes and six species of invertebrates were collected during the study. The blue crab (Callinectes sapidus) and the gulf menhaden (Brevoortia patronus) were the only commercial species that were numerous components of the living biomass export. Centrarchid species, notably the largemouth bass (Micropterus salmoides) and the

bluegill (Lepomis macrochirus) were the dominant predators during most of the year. They fed heavily on marsh-creek species including the common fiddler crab (Uca pugnax) and the grass shrimp (Palaemonetes pugio).

The marsh-creek system imported particulate detritus via the tidal creek when heavy river discharge or strong winds produced high concentrations of suspended particulate matter in the water and exported detritus when good weather prevailed and the detrital concentration of the water was low. (A.A.-modified)

Keywords: tidal creek, detritus, biomass, tidal marshes, crabs, sippi menhaden, Mississippi

III-D-13

Heinle, D.R., and D.A. Flemer. 1976. Flows of materials between poorly flooded tidal marshes and an estuary. *Marine Biology* 35:359-373.

Flows of particulate carbon, nitrogen, phosphorus, chlorophyll a, crude fiber, carbohydrate, adenosine tri-phosphate, dissolved nitrogen, and phosphorus between Gotts' marsh and the Paxtuent estuary, Maryland, were measured over a 2-year period. Virtually no carbon was exchanged from this low-salinity marsh. Net flows of nitrogen and phosphorus were from the marsh to the estuary, principally in dissolved forms. (J.B.)

Keywords: mineral nutrition, phosphorus, carbon, chlorophyll a, coastal marshes, estuaries, Maryland

III-D-14

Woodwell, G.M., P.H. Rich, and C.A. Hall. 1973. Carbon in estuaries. Pages 221-240 in G.M. Woodwell and E.V. Pecan, eds., *Carbon and the biosphere*. Technical Information Center, Office of Information Services, United States Atomic Energy Commission.

A crude estimate of the world's estuaries indicates a total area of about $1.7 \times 10^6 \text{ km}^2$ of which $3.8 \times 10^6 \text{ km}^2$ is marsh and $1.4 \times 10^6 \text{ km}^2$ is open water. Despite the large amount of research on estuaries in recent decades, there is little basis for an evaluation of equations that define relationships between net primary production gross projection, and various segments of total respiration in estuaries.

A survey of the literature suggests that net primary production of estuarine marshes ranges from low rates averaging 1000 g (dry organic matter)/year in high latitudes to as much as 5000 g in the tropics. An average middle-latitude net production for the shallow water of estuaries seems to be about 1500 g (dry organic matter)/year.

Estuarine areas occupy about .25 percent of the earth's surface. About 20 percent of the estuarine area is marsh, and the other 80 percent is open water. Thus, world net production of estuarine areas is probably about 3.1×10^9 metric tons of organic matter annually, or about two percent of the world net production.

Research at Flax Pond, a 50 hectare marsh open to Long Island Sound, suggests that there is no significant outwelling of fixed carbon from estuarine marshes into coastal waters. In fact, the flux may be in the opposite direction, with the marsh removing fixed carbon from tidal waters. If this relationship applies generally and sediments are accumulating, net ecosystem production (defined as gross production and net production in minus total respiration and net production out) must be positive for the estuaries of the world. Estuaries appear to be centers of high primary production, high metabolism, and centers of sedimentation; they may not normally be centers of outwelling of fixed carbon into coastal waters. (J.B.)

Keywords: carbon, estuaries, tidal marshes, primary productivity, outwelling, Long Island, U.S. coastal regions

E. Detritus Feeders

III-E-1

Odum, W.E. 1968. The ecological significance of fine particle selection by striped mullet, Mugil cephalus. Limnology and Oceanography 13:92-98.

By tracer experiments and a comparison of sediment and stomach content particle sizes, Mugil cephalus Linnaeus is shown to prefer very fine particles wherever sediments are involved in feeding. It is suggested that these small inorganic and plant detrital sediment particles are much richer both in absorbed organic material and in absorbed bacteria, protozoa, and other microorganisms than the coarser material that the mullet rejects. This selectivity results in substantially higher organic value of the stomach contents than of the sediments.

It has been established that the major contents of the stomach comprise three categories: 1) microalgae including epiphytic and benthic diatoms, dinoflagellates, green and blue-green algae, 2) decaying plant detritus, and 3) inorganic sediment particles. Microalgae are regarded as the primary source of nutrition, although plant detritus appears to be quite important in estuarine areas. (A.A.-expanded)

Keywords: striped mullet, detritus, microalgae

III-E-2

Darnell, R.M. 1961. Trophic spectrum of an estuarine community, based on studies of Lake Pontchartrain, Louisiana. *Ecology* 42:553-568.

One of the fundamental questions in aquatic ecology is the problem of community nutrition. Several recent investigators have achieved a high degree of success in working out quantitative aspects of primary production in natural aquatic communities. However, studies of the problems of secondary production have not yielded results of the same consequence. This has been due to the absence of good quantitative methods of analyzing consumer nutrition and to the complexity of the nutritional relations among the consumer species. With a few notable exceptions, comprehensive data regarding the nutrition of a large share of the consumers of a given aquatic community have not been available, and overall patterns of the trophic relationships among consumer species have not been well understood. As a part of a study conducted in Lake Pontchartrain, 1953-55, food habits of 35 of the most important consumer species were investigated to achieve a more thorough understanding of the problem of consumer nutrition and its relationship to primary production in a complex natural community. The results of the food studies of the various species have been published, and the present work is an attempt to interpret these results in the context of the total community.

Principal findings are summarized as follows:

1. The Lake Pontchartrain community is a broadly open system, exchanging nutrients, producers, and consumers with adjacent fresh-water and saltwater areas, as well as with neighboring marshes and swamps.
2. Consumers within the lake apparently depend in great measure upon primary production which takes place outside the lake. Hence, the estuarine community may be trophically unbalanced.
3. The most conspicuous single food item in the diets of the consumers of this community is organic detritus with its attendant bacteria.
4. Individual species do not appear to conform to specific trophic levels because of the following considerations:
 - a. Most, if not all, of the major consumer species are omnivorous.
 - b. Consumers select food opportunistically.
 - c. Ontogenetic changes occur in the food habits of the consumers.
 - d. Organic detritus is important in the nutrition of the consumer species, some being largely dependent on it.

e. Organic detritus has a complex origin.

5. An alternative model of the trophic relationships of the community is presented. The observed food of each species is presented as a continuum in which each type of food can be represented quantitatively and comparatively.

6. The abundant consumer species of the Lake Pontchartrain community comprise two groups: those that feed heavily upon organic detritus and those that exhibit a broad range of food tolerance. (G.S. and author's summary)

Keywords: estuarine community, aquatic ecosystem, primary production, trophic relationships, Louisiana

III-E-3

Darnell, R.M. 1958. Food habitats of fishes and larger invertebrates of Lake Pontchartrain, Louisiana, an estuarine community. Publications of the Institute of Marine Science, University of Texas 5:353-416.

This report deals with food habitats of 35 estuarine species of fishes and invertebrates found in Lake Pontchartrain, Louisiana. About 1,399 detailed quantitative analyses and 100 quantitative analyses were carried out. Nearly all the specimens were collected within a 14-month period.

The food studies revealed two primary food chains within Lake Ponchartrain. The first pathway proceeds from copepods (Acartia) through small fishes (Anchoa, Brevoortia, very young sciaenids, etc.), to larger predators. The second proceeds from small benthic invertebrates through larger invertebrates and small bottom-dwelling fishes (catfishes, young sciaenids, etc.), to the same large predators. Organic detritus, which was prominent in the food of the fishes and larger invertebrates, probably also serves as an important source of nutrition for the copepods and small benthic invertebrates of this turbid estuary. Such detritus has a very complex origin and it has been shown by other workers to be rich in bacteria.

An ontogenetic progression of food stages was clearly demonstrated for several of the well studied species, and for one species (Atlantic croaker) as many as four distinct nutritional stages were recognized. Within a given stage considerable substitution of food items was often observed. In some cases it was possible to correlate ontogenetic changes in food utilization with changes in morphology, habitat, feeding time, and behavior. As a result of their highly varied diets including much detritus, most, if not all, of the species examined are considered to be omnivorous. Distinct trophic levels (in the sense of Lindeman) were not recognizable in this estuarine community.

The physical environment of Lake Pontchartrain was found to be characterized by moderate temperature, generally low salinity, and very high turbidity, although considerable variations in these factors were noted.

The species of fishes and invertebrates that were considered are identified as follows: bull shark, longnose gar, spotted gar, alligator gar, bigeye herring, gulf menhaden, gizzard shad, threadfin shad, southern bay anchovy, gaff-topsail catfish, sea catfish, blue catfish, channel catfish, Atlantic needlefish, striped mullet, silverside, yellow bass, largemouth bass, common jack, freshwater drum, silver perch, sand squeteague, spotted squeteague, spot, Atlantic croaker, black drum, red drum, gulf sheepshead, pinfish, southern flounder, hogchoker, common rangia (clam), white shrimp, river shrimp, and blue crab. (H.D. and author's summary).

Keywords: estuarine community, fishes, invertebrates, food habits, Louisiana

III-E-4

Odum, W.E., and E.J. Heald. 1975. The detritus-based food web of an estuarine mangrove community. Pages 265-286 in L.E. Cronin, ed., Estuarine research, Vol. 1. Academic Press, New York.

This paper is an attempt to construct a conceptual model of the food web of an estuarine mangrove community. The objective is to ascertain the importance of vascular plant detritus to the heterotrophic community.

From stomach-content data most of the important organisms of the estuary were arranged into the following groups: herbivores, omnivores, and three levels of carnivores. Most species function at more than one trophic level.

Of about 120 species examined, roughly one-third can be classified as detritus consumers. These are defined as organisms whose digestive-tract contents averaged at least 20 percent vascular plant detritus by volume on an annual basis. These detritus consumers included herbivorous and omnivorous species of crustaceans, mollusks, insect larvae, nematodes, polychaetes, and a few fishes. They appeared capable of digesting algae, portions of vascular plant detritus particles, micro-organisms and, perhaps, dissolved substances sorbed upon inorganic particles.

A schematic diagram of the North River food web suggests that the principal flow of energy is along the route: mangrove leaf detritus, bacteria and fungi, detritus consumers, lower carnivore, higher carnivores. (A.A.)

Keywords: detritus, food web, estuaries, mangroves

III-L-5

Teal, J.M., and J. Kanwisher. 1961. Gas exchange in a Georgia salt marsh. *Limnology and Oceanography* 6:388-399.

There is a broad band of salt marshes running along the southeast coast of the United States which, because of their relative simplicity, make good subjects for ecological research. Most of the primary production can be attributed to Spartina alterniflora, the only important higher plant growing in the marshes. The remainder is due to the algae growing on the surface of the marsh mud. Considerable detritus is formed from products of primary production and much of this accumulates on the mud surface producing a black mud, rich in organic matter. In and on this mud live most of the marsh consumers from fiddler crabs to nematodes and bacteria. This paper is concerned with the role of the mud and its micro-fauna in the marsh energy budget and also with some of the properties of the mud that are important to organisms living in it. (A.A.-modified)

Keywords: gas exchange, salt marsh, Spartina alterniflora, Georgia

III-E-6

Teal, J.M. 1959. Energy flow in the salt marsh ecosystem. Pages 101-107 in Proceedings of the salt marsh conference, Sapelo Island, Georgia. University of Georgia, Athens.

An energy flow diagram was constructed to evaluate the role of the salt marsh in the estuary-marsh system along the Georgia coast and to aid in understanding the trophic relationships of the various organisms living in the marsh.

The value for total light energy was divided equally between the two primary producers on the marsh, Spartina alterniflora and algae living on the mud surface. Data for Spartina production were taken from previous measurements of the standing crop in the Sapelo Island marshes. The data for the algae were taken from a previous study, as were the data for assimilation and transformation of energy by insects.

Marsh consumers transform less than half (46 percent) of the total primary production of the marsh. This means the salt marsh is producing and exporting enough energy to support a larger community than that living on the marsh. Much of the bacterial action upon Spartina, considered a part of the marsh system, actually takes place in the water. Sufficient energy is fixed in the salt marsh to support a large population of shrimp, fish and bottom organisms in the tidal creeks and estuaries and in the Georgia salt marsh region. Energy production by the local estuarine plankton community, as measured by oxygen changes, is negative. This suggests that most aquatic organisms

must obtain their energy from some source, such as the marsh.

The aquatic forms, because of the flushing of the marsh surface with every tide, have a large part of the marsh production brought to them before the marsh consumers have a chance to eat it. A similar relationship between marsh and associated waters would not necessarily be expected in a region where the great extent of the marsh was not regularly flooded.

Keywords: energy flow, salt marsh ecosystem, estuaries, Spartina, Georgia

III-E-7

Teal, J.M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624.

The Marine Institute of the University of Georgia has focused its attention on marshland located on Sapelo Island off the Georgia coast. Construction of a picture of the energy flow through marsh organisms is now possible through data supplied by these studies.

The marsh was divided into five regions for study. They are: streamside marsh; creek bank; levee marsh; short-Spartina marsh; and Salicornia marsh. Marsh fauna and the food web are examined in detail, and an extensive listing of macro-fauna is provided.

The herbivorous fauna of many ecosystems can be divided into two groups: those that feed directly on living plants and those that feed on plants only after the plants have died and fallen to the ground. The marsh fauna may be grouped in a similar manner.

A group of insects lives and feeds directly upon the living Spartina: Orchelimum, eating the tissues; and Prokelisia, sucking the plant juices. These and their less important associates support the spiders, wrens, and nesting sparrows. A different group lives at the level of the mud surface and feeds on the detritus formed by bacterial decomposition of Spartina and on algae. These mud dwelling groups function mostly as primary consumers, although the detritus also contains animal remains and numbers of the bacteria that help break the Spartina into small pieces. The carnivores preying on the algal and detritus group are principally mud crabs, raccoons, and rails.

The species of the detritus-algae feeding group that are important in the economy of the marsh are the fiddler crabs, oligochaetes, Littorina, and the nematodes among the deposit feeders; and Modiolus and Manayunkia among the suspension feeders. Thus, the community consists of two parts,

one deriving its energy directly from the living Spartina and the other deriving its energy from detritus and algae.

Maintenance of population and community stability are shown to be paramount factors in preservation of the ecosystem. (H.D.)

Keywords: energy flow, salt marsh ecosystem, detritus, food web, Georgia

III-E-8

Shanholtzer, S.F. 1973. Energy flow, food habits and population dynamics of Uca pugnax in a salt marsh system. Ph.D. Thesis. University of Georgia. 100 pp. (Diss. Abstr. 34:3755-B)

The energy budget, food habits and population dynamics of Uca pugnax have been studied in the Georgia salt marshes. Uca pugnax, a detritivore, serves as an important link in the highly productive detrital salt marsh energy budget, accounting for 15 percent or more of the secondary consumption. This energy, traceable to both major producers of the marsh (Spartina alterniflora and benthic diatoms), is extracted from surface sediments and made available to terrestrial, marsh and aquatic consumers through predation, parasitism, or saprophagy.

Fiddler crabs were known to be omnivorous, feeding on algae, detritus, bacteria, and animal remains. The direct food potential of the cellulytic detritus of S. alterniflora was implicated by the presence of cellulase in the intestinal tract of U. pugnax. The high incidence of fungi in the ingested materials provides evidence for another energy pathway from S. alterniflora to U. pugnax not previously considered.

A model of energy flow through a U. pugnax population has been constructed. This has served to produce estimates of energy flow and its partitioning through the population and marsh system. (A.A.-modified)

Keywords: energy flow, food habits, fiddler crabs, detritus, salt marshes, Georgia

III-E-9

Brickman, L.M. 1972. Base food chain relationships in coastal salt marsh ecosystems. Ph.D. Thesis. Lehigh University. 190 pp. (Diss. Abstr. 33:2185-B)

The distribution and abundance of the meiobenthos was studied monthly from October 1969 to December 1970 at six stations within the Dividing Creek watershed in Cumberland County, New Jersey. Three stations were located subtidally in the upper, middle, and lower reaches of Dividing Creek, and one station was located in the Spartina alterniflora

marsh bordering the creek. Two additional stations were situated in an adjacent diked marsh that is managed for salt hay production. One is in a drainage ditch, and the other is on the S. patens marsh. The total number of individuals ranged from 36-10,594/10cm² and the dry weight biomass from 0.62-17.59mg/10cm². Free living nematodes, which comprised 78.3 percent of the total numbers and 62.3 percent of the biomass, were the most abundant organisms collected at all the stations but those located in the middle and upper reaches of Dividing Creek. Harpacticoid copepods were second in overall abundance, comprising 14.8 percent of the total numbers and 14.7 percent of the total biomass, and were the most abundant organism at the remaining two stations.

Total population values were highest in the late spring and summer, and lowest in the winter. Nematodes inhabiting the creek did not exhibit a distinct seasonal pattern. Copepod abundance was related to reproductive cycles and predation pressure by members of the macrofauna and natant forms. The meiofauna were restricted to the upper layers of the substrate by the strongly reducing character of the sedimentary environment except at the marsh stations where oxygenation of the sediment by the Spartina root systems occurred.

Thirty-five species of harpacticoid copepods were collected during the survey. Pseudobradia pulchra, Scotolana canadensis, and Paronchocamptus huntsmani dominated the fauna in Dividing Creek. Nannopus palustris, Nitocra spinipes, Schizopera knabeni and Sigmatidium minor were dominant in the S. alterniflora marsh. Cletocamptus bicolor was dominant in the drainage ditch; and Nitocra spinipes, in the S. patens marsh. Four distinct harpacticoid assemblages are described: mesohaline estuary, salt marsh, drainage ditch, and modified salt marsh. The degree of physical stress within the ecosystem is reflected by the low overall diversity of the harpacticoid copepod communities. Except for the diked marsh, the meiofauna inhabiting the Dividing Creek watershed reflect the high productivity of the estuarine environment. (A.A.)

Keywords: food chain, Spartina alterniflora, S. patens, meiofauna, estuary, New Jersey

III-E-10

Adams, S.M., and J.W. Angelovic. 1970. Assimilation of detritus and its associated bacteria by three species of estuarine animals. Chesapeake Science 11:249-254.

The assimilation of detritus and its associated bacteria by three species of macrofauna that are abundant in eel grass beds during the summer was investigated in a laboratory study. The amount of carbon dioxide respired per milligram of dry body weight by animals that fed on different types of labeled food was compared to determine the relative amount of assimilation of a particular food. Animals were fed sterilized

and unsterilized detritus labeled with carbon to determine if they assimilated either the detritus per se or its associated bacteria as food.

All three species ingested and assimilated detritus. After three days of feeding, a small gastropod, Bittium varium, had ingested and assimilated more detritus per mg of body weight than either the grass shrimp, Palaemonetes pugio, or the polychaete, Glycera dibranchiata. Both Palaemonetes and Bittium assimilated carbon from labeled bacteria associated with the detritus as well as from the labeled detritus. All three species assimilated some carbon from soluble sources.

On the basis of the data presented, it appears that detritus may be an important food source for these animals in nature since all three species assimilated more carbon from detritus than from undecomposed eel grass. Because these animals are able to assimilate detritus and because detritus is very abundant in the eel grass beds where they are the dominant species, the detritus could be one of their main sources of energy. (A.A. and summary)

Keywords: detritus, macrofauna, food chain, estuaries

III-E-11

Kost, A.B., and A.W. Knight. 1975. The food of Neomysis mercedis Holmes in the Sacramento-San Joaquin estuary. California Fish and Game 61(1):35-46.

Gut contents were determined in approximately 1,500 opossum shrimp from the Sacramento-San Joaquin estuary. The shrimp, obtained from 12 stations over a 13-month period, were 2 to 17 mm long. The most abundant items in the gut were detritus and diatoms. Origin of the detritus was not determined. The percentage of detritus relative to diatoms was greater in winter than in summer and increased with shrimp size. Of the 40 kinds of diatoms encountered in the guts of opossum shrimp, two diatoms--Coscinodiscus and Melosira--were far more abundant than the rest. The former was the most important diatom in the guts of shrimp from the lower Delta and Suisun Bay stations.

Previous reports indicate that mysid shrimp are capable of utilizing a wide variety of foods. The results of this study are consistent with these reports. (L.H.)

Keywords: estuaries, opossum shrimp, diatoms, California

III-E-12

Jones, R.R. 1973. Utilization of Louisiana estuarine sediments as a source of nutrition for the brown shrimp Penaeus aztecus. Ph.D. Thesis. Louisiana State University. 140 pp. (Diss. Abstr. 35:1127-B)

An investigation of food habits of juvenile Penaeus aztecus was conducted in Airplane Lake, a small tidal pond in the marsh bordering Barataria Bay, Louisiana. Results indicated that younger juveniles were encounter feeders utilizing the detrital organics and associated microfauna of the bottom substrate. As the shrimp matured, they became increasingly predatory on benthic macrofauna. Change to a predatory feeding habit was reflected by increase in organic assimilation efficiency. Juvenile shrimp fed most effectively in the shore zone of Airplane Lake where concentrations of organic detritus, microorganisms and benthic meiofauna were highest.

Selection for organic particles and assimilation efficiency increased with shrimp size. An average organic assimilation efficiency of 41 percent in larger juveniles (65-84 mm) was about double the efficiency recorded in smaller juveniles (21 percent at 25-44 mm). In contrast, protein assimilation efficiency declined with size.

Visual and chemical analyses of particulate content of sediment revealed greatest concentrations of organic detritus and benthic meiofauna along the shoreline. Highest protein concentrations were associated with fine detrital fractions below 160 microns particle diameter. (A.A.)

Keywords: detritus, brown shrimp, Louisiana

III-E-13

Welsh, B.L. 1973. The grass shrimp, Palaemonetes pugio, as a major component of salt marsh ecosystem. Ph.D. Thesis. University of Rhode Island. 97 pp. (Diss. Abstr. 34:2764-B)

The grass shrimp, Palaemonetes pugio, was studied in its role as a dominant species uniquely adapted to a highly stressed tidal marsh embayment. Monthly sampling of length and dry weight revealed that its life cycle was a single year, with spawning in May, June and July and heaviest growth in late summer and fall. Mark and recapture estimates conducted quarterly and quadrat net estimates calculated monthly indicated that shrimp were present throughout the year with peak densities in the fall (over 1.2 million in 2-1/2 acres in October). Production of biomass (growth) equalled loss to predation (including decomposition) over the annual cycle.

Microcosm studies and observations by scanning electron microscope revealed that the shrimp mascerated detritus into a heterogeneous assortment of uneaten particles by plucking away the cellular matrix from surfaces

of large detrital fragments. This action provided cavities that were heavily invaded by pennate diatoms and particles that became suspended in the water column and populated by bacteria.

Nutrient analyses indicated that the shrimp were excreting large quantities of ammonia, phosphate, nitrate and nitrite, which, together with the dissolved organic material (DOM) release, is presumably responsible for the heavy growth of microflora and increased protein fraction in both feces and large and small uneaten detrital fragments.

Palaemonetes pugio, while supporting its own trophic requirements, accelerates the breakdown of detritus, preventing blockages or bottlenecks that might occur from the pulses of emergent grass and macroalgal detritus that occur in the embayment. This repackaging into feces, heterogeneous fragments, DOM and shrimp biomass makes detrital energy available at a variety of trophic levels, smoothing out the organic pulses over time and space, and raising the efficiency of transfer to the food web. By milling and fertilizing the detrital substrate, P. pugio enhances microbial settlement on the detritus, which further raises its nutritional value. The special adaptation of P. pugio to decomposer systems limits predation and competition, allowing the shrimp to develop the large populations necessary to carry out its role effectively. (A.A.-modified)

Keywords: salt marsh ecosystem, nutrient values, grass shrimp

III-E-14

Odum, W.E. 1971. Pathways of energy flow in a south Florida estuary. University of Miami Sea Grant Technical Bulletin No. 7. 162 pp.

The feeding habits of more than eighty species of animals were monitored from stomach content examinations of over 7,000 individuals made over a period of 10 months. From a consideration of these feeding habits on an annual basis, the organisms were classified as herbivores, omnivores, primary carnivores, middle carnivores, and higher carnivores. The principal source of food for the aquatic animal community of the Everglades mangrove belt is vascular plant detritus originating principally from red mangrove leaves. During the process of decay and microbial colonization, the detritus particles increase in relative protein content and in caloric value. There are at least four pathways by which freshly fallen mangrove leaves are utilized by heterotrophs: (A) dissolved organic substances to microorganisms to higher consumers, (B) dissolved organic substances to sorption on sediment and aged detritus particles to higher consumers, (C) leaf material to higher consumers, (D) leaf material to bacteria and fungi to higher consumers. The last pathway is believed to be the most important. There exists a key group of omnivorous estuarine organisms which ingest quantities of vascular plant detritus. In the North River estuary, this key group of detritus consumers includes amphipods, mysids, cumaceans, ostracods, chironomid midge larvae, harpacticoid and planktonic copepods, snapping shrimp,

caridean shrimp, penaeid shrimp, crabs, filter-feeding bivalves, and a few species of fishes. The omnivorous detritus consumers appear to obtain nutrition primarily from the microorganisms adsorbed upon detritus particles. The destruction of mangrove forests will remove a source of food input into an estuary and directly limit the production of detritus consumers and those predators that feed upon them. (A.A.)

Keywords: mangrove, energy flow, food chain, estuaries, Florida

III-E-15

Kuenzler, E.J. 1961. Phosphorous budget of a mussel population. *Limnology and Oceanography* 6:400-415.

The common horse mussel (Modiolus demissus), which is abundant in the marshes, is extremely important in the phosphorous cycle. In filtering water to obtain its food, the mussel deposits huge quantities of organic particles by producing pseudofeces that sink to the bottom. Organic matter is thus retained in the marsh and made readily available to the algae and fiddler crabs. This study was one of the earliest to suggest the great complexity of the food chain in estuarine areas. (J.B.)

Keywords: food chain, horse mussel, phosphorous

III-E-16

Heinle, D.R., D.A. Flemer, J.F. Ustach, R.A. Murtagh, and R.P. Harris. 1973. The role of organic debris and associated microorganisms in pelagic estuarine food chains. Maryland Water Resources Research Center, College Park, Technical Report No. 22. 123 pp.

Production on marshes adjacent to the upper Patuxent estuary was 1,000 to 1,500 grams dry weight per m² per year. Approximately 6 to 9 percent of the annual production was exported to the estuary as particulate carbon. Production was comparable to other marsh systems, but export (as percentage of production) was less, probably due to poor tidal exchange. In spite of the relatively low percentage of their fixed carbon contributed to the estuary, the marshes provide about one-third of the total carbon budget in the upper Patuxent. A large portion of the marsh carbon enters the estuarine system in early spring when levels of algal primary production are low. Substantial production of the calanoid copepod Eurytemora affinis occurs with detrital carbon as the apparent food base. Feeding experiments indicate that E. affinis can reproduce when fed a diet of detritus enriched with bacteria and protozoa, or when fed only protozoa. Diets of detritus and microorganisms alone were seldom equal to algal controls, however, suggesting that detritus provides only part of the carbon requirement.

A harpacticoid copepod, Scottolana canadensis, was found less capable of using detritus and associated microorganisms, but could obtain some energy from that source. (A.A.)

Keywords: food chain, detritus, estuaries, productivity, Maryland

III-E-17

Fox, D.L. 1950. Comparative metabolism of organic detritus by inshore animals. Ecology 31:100-108.

This report considers the sources, character, and disposition of marine detrital organic matter and the subsequent metabolism of detritus by inshore animals. The author divides the various species of detritus feeders into three main groups: animals that filter detritus through use of cilia or net structures; animals that graze upon the ocean floor utilizing tentacles or a muscular pharynx (sucking); and animals that feed by scraping adherent material from rocks, shells, pilings and other submerged surfaces. Several findings are reported.

The sizes of populations that will be supported in a marine inshore area are dependent upon the quantities of organic detritus that may serve as food, either directly or by contributing to the total carbon budget.

Great numbers of marine invertebrates feed primarily upon organic detritus. They obtain it by (1) filtering such colloidal or other fine particulate material from the water, (2) swallowing whole mud, sand and other inert material to which the organic matter is adsorbed, or (3) scraping it from extensive immersed surfaces.

Biochromes, such as red, orange or yellow carotenoids or greenish breakdown products of chlorophyll, provide valuable means of studying the comparative biochemistry of nutrition and assimilation, especially as derived from suspended or precipitated detrital materials.

While xanthophyllic carotenoids are more common than carotenes in fresh, suspended plankton and detritus and in numerous detritus eaters, carotenes are the predominating carotenoids of buried marine muds, and of a few detritophagous animals.

Comparisons are drawn between two typical marine detritus feeders: (a) mussels, which filter vast quantities of water annually, removing therefrom the finely suspended organic matter from which some of the xanthophylls are assimilated and the carotenes quantitatively rejected, and (b) the beach-annelid, Thoracophelia, colonies of which cycle tons of sand annually through the alimentary tract, gaining nutrition from the adsorbed film of colloidal organic matter, from which β -carotene is selectively assimilated, while xanthophylls are rejected and largely destroyed.

Such biological agents and their countless allies alter the chemical and physical nature of both water and floor, not only near the coast but at considerable distances out from shore. (Author's summary and H.D.)

Keywords: detritus, marine invertebrates, inshore animals

III-E-18

Marples, T.G. 1966. A radionuclide tracer study of arthropod food chains in a Spartina salt marsh ecosystem. Ecology 47:270-277.

The arthropods of the Spartina marsh obtain their energy either by grazing on the marsh grass or by eating the microbial-rich organic detritus that is largely derived from the dead Spartina. The two energy sources were labeled with phosphorus in separate quadrats and the subsequent buildup of radioactivity followed in the arthropod populations. Four species of insects were dominant grazing organisms (one Orthoptera, two Hemiptera, and one Homoptera), while two families of Diptera (Dolichopodidae and Ephydriidae) included the important insects associated with the detritus complex. The spiders were the important carnivores and obtained their energy from both the detritus and grazing food chains. (A.A.)

Keywords: arthropods, food chain, Spartina, salt marsh ecosystem, detritus

III-E-19

Reeve, M.R. 1975. The ecological significance of the zooplankton in the shallow subtropical waters of south Florida. Pages 352-371 in L.E. Cronin, ed. Estuarine research, Vol. 1. Academic Press, New York.

Much emphasis has been placed on the imported detrital and benthic sea grasses in the biological economy of shallow subtropical inshore waters. This report seeks to present the existing data on plankton, which indicate that the shallow water column may support planktonic production at least as large as some much deeper, colder-water, inshore regions. It is suggested that plankton organisms are important in the utilization of this material in the marine ecosystem both by their rapid uptake of dissolved organics flushed out from the land and released from sediments and by the possible ability of the ultra-microzooplankton to graze on detrital-bacterial aggregations in the water column. In two adjacent areas substantial differences in plankton biomass could be correlated with freshwater runoff. In the low biomass region, summer temperatures were associated with severe depressions of macroplankton populations. (A.A.)

Keywords: zooplankton, productivity, estuarine systems, detritus, Florida

III-E-20

Ellison, R.L. 1972. Ammobaculites, foraminiferal proprietor of Chesapeake Bay estuaries. Pages 247-262 in B.W. Nelson, ed., Environmental framework of coastal plain estuaries. The Geological Society of America, Columbia, South Carolina.

In the central parts of Virginia, estuaries that are tributaries of Chesapeake Bay, a foraminiferal facies characterized by Ammobaculites is replaced seaward by an Elphidium facies, upstream by a Diffugia facies, and laterally in the marshes by a Miliammina and Ammonastuta facies. Within the area where Ammobaculites are most abundant, foraminiferal tests commonly number between one and ten thousand per 20 cubic centimeters, and Ammobaculites comprise nearly 100 percent of the total. Locally, empty tests and living specimens aggregate in clumps measuring from 15 to 150 meters in diameter. The genus is distributed vertically from 100 centimeters above the estuary floor, where it lives in eelgrass, to at least 9 centimeters below the bottom, where it subsists in organic-rich muds. Concentrations of empty tests in estuarine samples from Virginia and Maryland suggest that Ammobaculites must have a moderately high annual turnover while thriving on the "vegetable soup" of estuaries.

Ammobaculites crassus Warren dominates foraminiferal communities in the Chesapeake Bay area wherever salinities are between one and 15 percent. The Ammobaculites and contiguous facies shift along the estuary in response to seasonal salinity changes, and faunal patterns across the estuary conform to the asymmetrical distribution of salinity induced by Coriolis effects. High temperatures, up to 14°C above the normal in thermally polluted waters, have only limited effect on Ammobaculites. Comparison with other estuaries suggests that the dominance of Ammobaculites depends on salinity, geographic location or physiographic setting, and the presence of organic detritus. (A.A.)

Keywords: estuaries, foraminiferal facies, Chesapeake Bay

III-E-21

Stephens, G.C. 1967. Dissolved organic material as a nutritional source for marine and estuarine invertebrates. Pages 367-373 in G.H. Lauff, ed., Estuaries. American Association for the Advancement of Science, Washington, D.C.

Much organic material other than that represented by the biomass of the various trophic levels of the community is present in the environment. In an inshore marine community, this material includes particulate detritus, material of colloidal dimensions, and organic material in solution in sea water. This paper summarizes some recent evidence concerning a possible nutritive role of organic material in true solu-

tion. Attention was confined to estimates of free amino acids in sea water.

Twelve genera of soft-bodied freshwater invertebrates were studied in the author's laboratory, where it was observed that the rate of uptake of amino acids was much less than that observed in marine organisms. Further, none of the genera were capable of removing more than that observed for marine organisms. The freshwater invertebrates were incapable of removing more than a few percent of added labeled glucose or amino acids over a period of 24 hours. Two species of brackish-water nereids were studied with respect to their ability to accumulate glycine at different salinities. Both Nereis succinea and Nereis limnicola were capable of accumulating this compound at permissive chlorosities of the medium. It appears that the processes that underlie osmotic regulation are incompatible with the rapid accumulation of amino acids from the ambient medium, and essentially all marine invertebrates examined exhibited such accumulation while none of the freshwater invertebrates examined showed this tendency.

The uptake of organic compounds of low molecular weight appears to be a significant supplemental source of reduced carbon for several marine animals. Comparison of the material available to the animals at concentrations characteristic of their environment and the amount of material necessary to account for oxidative metabolism supports this position. Finally, there is qualitative evidence that such material can enter oxidative and synthetic pathways in the animals studied. (H.D.)

Keywords: nutritional sources, invertebrates, detritus, biomass

III-E-22

Craven, T., and L.G. Williams. 1973. The role of Spartina detritus in the character of plankton assemblages of the Mobile Bay estuary. Association of Southeastern Biologists Bulletin 20:47. (Abstr.)

Bacterial conglomerates of decomposing Spartina were associated with a population density and structure of plankters having wide variations among the salt marsh, Mississippi Sound, and the coastal near-shore biota. High turbidities, high bacterial densities, and large suspended organic particles were common in the Spartina marsh. Mississippi Sound and the near-shore Gulf showed low densities of suspended detrital particulates, but much higher densities of phyto- and zooplankton. (A.A.)

Keywords: detritus, Spartina, plankton, estuaries, Mobile Bay

III-E-23

Elliot, P.B., and S.S. Bamforth. 1975. Interstitial protozoa and algae of Louisiana salt marshes. *Journal of Protozoology* 22:514-519.

Interstitial ciliate distributions were studied in Louisiana salt marshes and stagnant connecting pools dominated by Spartina and Distichlis spicata. The sediments constitute a "sulphide biome." The abundance of nutrients in the sulfide biome provides habitable conditions for all the major groups of microflora. These, in turn, support nutritionally diverse predatory ciliate populations. (J.B.)

Keywords: Spartina, Distichlis spicata, algae, Louisiana

III-E-24

Lackey, J.B. 1967. The microbiota of estuaries and their roles. Pages 291-302 in G.H. Lauff, ed., *Estuaries*. American Association for the Advancement of Science, Washington, D.C.

This report covers the species and roles of bacteria, algae, and protozoa found in estuarine environments.

Food is brought into estuaries by the land-fed streams, and the death of plants and animals adds further organic matter. One result is a large population of bacteria both in the water and in the sediments. This population, aside from its function of mineralization, may become food for large animals. There is increasing evidence that soluble organic food is utilized by both chlorophyll-containing organisms and colorless saprozoites, such as the large populations of colorless euglenids in the sediment-water interface. Eubacteriales and yeasts are food for large numbers of colorless Monas and Pteridomonas. The former is ubiquitous, but the latter is rarely seen. Thus, specialized substrates result in specialized biotas.

Despite a small number of genera and species, the three orders of colorless zooflagellates often attain large populations in estuaries, where their principal functions are the consumption of bacteria and subsequent utilization by higher orders in the food chain. (H.D.)

Keywords: estuaries, microbiota, food chain

III-E-25

Peters, D.S., and M.A. Kjelson. 1975. Consumption and utilization of food by various postlarval and juvenile fishes of North Carolina estuaries. Pages 448-472 in L.E. Cronin, ed., *Estuarine research*, Vol. 1. Academic Press, New York.

Production studies described in this paper are limited to determining diet composition, calculating food consumption rate, and describing environmental effects on the use of food for growth. Major problems in such studies include identifying food items in the gut and estimating their relative composition by weight or volume. Moderate-sized items can be identified to genus and species, provided adequate collections of local flora and fauna are available, but small, partially digested items may be impossible to identify. Organic detritus, a complex food resource consumed by many estuarine fish, is also difficult to identify and measure.

Detritus identification includes differentiating zooplankton, phytoplankton, and detritus, determining detrital origin, and differentiating between organic and inorganic material. The living microbial component, often coupled with nonliving detritus, is also difficult to identify and measure.

To evaluate the nature of food consumed by fish in the Newport River estuary, the authors examined stomach contents of juvenile pinfish, spot, and menhaden, three of the most abundant species present. Although samples were collected on different days at a variety of locations, there was little variation within species in the percent of animal, plant, and detrital material in the guts. Investigations showed that spot and pinfish ingested nearly the same percentages of animal, plant, and detrital particles and that the main food was animal particles. The main food of menhaden was detritus of unidentified origin, some of which may have been recently fragmented microalgae or protozoans. (B.W.)

Keywords: estuaries, fishes, food ecology, detritus, food habits, North Carolina

III-E-26

De Sylva, D.P. 1975. Nektonic food webs in estuaries. Pages 420-447 in L.E. Cronin, ed., *Estuarine research*, Vol. 1. Academic Press, New York.

Estuarine nekton includes primarily fishes, such as bluefish, jacks, ladyfish, menhaden, shad, mullet, salmon, snooks, striped bass, and tarpon. Squids, scallops, and natant crustaceans, including crabs, lobsters, and shrimp, have been considered as being nektonic in estuaries for short periods.

This article presents a summary of the literature on food studies. Thirty-six of seventy-six references examined discuss some aspect of

food webs in the estuary. Most of the references cited merely list foods found in the stomachs of various estuarine nekton.

Generalized food webs are basically fueled by either a phytoplankton source of energy or a detrital source. Recent advances in nektonic food studies have stressed detritus as a food source for tropical estuarine fishes, although some estuarine nekton depends solely on phytoplankton.

Most food studies have been done as an afterthought and not as part of a carefully planned experiment. Few of the studies cited permit comparison with other areas; none contain adequate environmental information. Some have gone into considerable detail, but these usually raise more questions than they answer. (B.W.)

Keywords: food webs, estuaries, fishes, marine invertebrates, U.S. coastal regions

III-E-27

Chadwick, H.K., W. Heubach, and D. Daniel. 1972. Invertebrate animals and their environmental requirements. Pages 26-35 in J.E. Skinner (compiler), Ecological studies of the Sacramento-San Joaquin estuary. California Department of Fish and Game, Delta Fish and Wildlife Protection Study Report No. 8.

Zooplankton, Neomysis, and zoobenthos are discussed in this chapter in terms of distribution and abundance and factors controlling abundance. Of the zooplankton, the following types probably depend on phytoplankton for food: protozoans, rotifers, and crustacean plankters. The crustacean plankters, however, may also use organic detritus for food.

Food habit studies of Neomysis are incomplete, but investigations thus far have disclosed that mysid stomachs contain phytoplankton, detritus, entomostracan parts, and, in some cases, entire rotifers.

Benthic animals or zoobenthos are primarily invertebrates that live in or on the bottom substrate of aquatic habitats. In the Sacramento-San Joaquin estuary they are an important source of food for some fish and for a number of waterfowl and shorebirds. (B.W.)

Keywords: invertebrates, zooplankton, marine organisms, food habits, California

III-E-28

Odum, W.E. 1970. Utilization of the direct grazing and plant detritus food chains by the striped mullet Mugil cephalus. Pages 222-240 in J.H. Steele, ed., Marine food chains. University of California Press, Berkeley.

Zooplankton are not the most important herbivore link in secondary production. In most cases, food chains are based on detritus derived from marsh grasses, sea grasses, macro-algae, and mangroves, or directly on the benthic and epiphytic microflora. Animals that are able to utilize such energy sources replace zooplankton as the critical herbivore link.

The striped mullet, Mugil cephalus, typically feeds either by sucking up the surface layer of mud or by grazing on submerged rock and plant surfaces. Studies have shown that the major stomach contents fall into three categories: (1) micro-algae, including epiphytic and benthic forms; (2) decaying plant detritus; and (3) inorganic sediment particles, which appear to function as a grinding paste in the degradation of plant cell walls in the pyloric stomach. There has not been a concerted attempt to analyze feeding habits in relation to the food available in the environment and how this relationship varies from one area to another.

For this study seven different environmental systems were chosen, and the mullet's diet analyzed for each system. Findings showed that M. cephalus is able to utilize either plant detritus or live plant material, depending on which is easier to exploit in a given situation. When faced with a choice between these two resources, M. cephalus fed almost exclusively on live plant material. (B.W.)

Keywords: fishes, food chains, zooplankton, detritus, food habits, California

III-E-29

Tenore, K.R. 1971. A technique for measuring detrital utilization by deposit feeding benthos. Page 237 in D.S. Gorsline, ed., Second national coastal and shallow water research conference; abstract vol. University of Southern California, Los Angeles. (Abstr.)

Many workers have emphasized the nutritive role of detritus in coastal systems, and any study of the energetics of the benthos must take into account this detrital energy flow. The consensus of benthic ecologists is that detritus, derived chiefly from the decay of shallow water rooted vegetation, is the basic nutritional source of shallow water benthos. Our knowledge of such functional relations is scant and investigations should aim at determining energy flow rates of the benthos.

However, traditional methods, e.g., gut analysis and differential growth studies, are unsuitable techniques to determine accurate rates of detrital energy flow. Even isotope tracer techniques need careful controls to account for errors due to carbon 14 leaching from the labeled detritus.

Rates of detrital utilization by different benthic species (Rangia cuneata, Macoma balthica, Nereis virens) were investigated using carbon 14-labeled detritus prepared from eel grass. The whole plants were collected and then cultured in the laboratory. Carbon 14 was introduced into the water and the cultures incubated for several days to allow the incorporation of the isotope. This procedure minimized leaching of carbon 14 during decomposition and also resulted in a more confident measure of incorporation. The eel grass was then dried and ground. At this point the detritus could be "aged" for different time periods to study effects of decomposition on detrital utilization. The labeled detritus was mixed with sediment and the organisms introduced. In order to ascertain and correct for carbon 14 uptake due to isotope leached from the decomposing detritus, control organisms placed in chambers with millipore filter sides were also placed in the experimental cultures. After a short period of time, e.g., 1 day, to minimize loss of activity through excretion and respiration, the animals were removed, and placed in sea water to allow voiding of the gut. Techniques of tissue digestion and solubilization were used and the activity measured by standard liquid scintillation methods. Corrections were made for activity due to the leached carbon 14 and for respiration.

Utilization rates were obtained for dominant organisms of a benthic community. This information, along with biomass data, was used to construct an energy budget for this detrital food chain of the benthic community. (A.A.)

Keywords: detritus, energy flow, estuarine organisms, biomass, food chain, U.S. coastal regions

F. Nutrient Turnover

III-F-1

Pomeroy, L.R. 1960. Residence time of dissolved phosphate in natural waters. Science 131:1731.

The residence time of dissolved phosphate in natural waters varies from approximately 0.05 to 200 hours. Short residence times are indicative of depleted phosphate, active metabolic activity, or both. The turnover rate of phosphate is between 0.1 and 1.0 mg of phosphorus per cubic meter, per hour, regardless of phosphate concentration,

except in biologically active systems where it is 1.0 to 20. The turnover rate of phosphate may be more important than the phosphate concentration in maintaining highly productive systems. (A.A.)

Keywords: residence time, mineral nutrition, coastal ecosystems

III-F-2

Kraeuter, J., and D.S. Haven. 1970. Fecal pellets of common invertebrates of lower York River and lower Chesapeake Bay, Virginia. Chesapeake Science 11:159-173.

Fecal pellets voided by 70 invertebrate species are described, 66 of these for the first time. Pellet size is related to size of animals, and linear regressions are given for two species. Pellet characteristics described are cross-sectional shape, sculpture, differentiation, composition, and shape. The morphology is specific for many animals. However, certain species void feces that are (1) diffuse, (2) morphologically inconsistent, or (3) lacking in differentiating characteristics. (A.A.)

Keywords: invertebrates, fecal pellets, Virginia

III-F-3

Frankenberg, D., S.L. Coles, and R.E. Johannes. 1967. The potential trophic significance of Callianassa major fecal pellets. Limnology and Oceanography 12:113-120.

The trophic significance of the fecal pellets of Callianassa major was investigated by measuring (1) the rates at which fecal material was produced, (2) its organic carbon and nitrogen content, and (3) its ingestion by other animals. Results indicate that 456 ± 118 fecal pellets are produced per burrow per day and from 175 ± 46 to $2,600 \pm 670$ pellets $m^{-2} day^{-1}$, depending on population density, and that an entire C. major population occupying an area of about $200,000 m^2$ produces about 280×10^6 pellets/day. The carbon and nitrogen contents of the pellets were 3.0 and 0.3 percent of their dry weight, respectively. Aging the pellets had no effect on their carbon content, but it halved the nitrogen content in 48 hours. Ingestion experiments indicated that fecal pellets were eaten by hermit crabs, probably by blue crabs, and possibly by several other beach inhabitants.

The results were used to calculate the rate at which organic carbon is made available in fecal pellets, and this rate was compared to

production rate measurements for local primary producers. The potential quantitative significance of fecal pellets as a food source is discussed. (A.A.)

Keywords: trophic relationships, fecal pellets, nutritional values, food source

III-F-4

Haven, D.S., and R. Morales-Alamo. 1966. Aspects of biodeposition by oysters and other invertebrate filter feeders. *Limnology and Oceanography* 11:487-498.

Quantities of suspended matter removed by oysters (Crassostrea virginica) and deposited as feces or pseudofeces varied seasonally, reaching maxima in September. Below 2.8°C, measurable quantities were not produced. At certain seasons, levels of suspended solids influenced quantities of biodeposits. Laboratory studies indicated that the oysters on 0.405 hectare of an estuarine bottom may produce up to 981 kg of feces and pseudofeces weekly. Of the particles, 95 percent were under 3 microns in diameter. All types of algal cells present in the surrounding water were represented. The deposits contained 77-91 percent inorganic matter, mostly illite, chlorite, and mixed-layer clays, 4-12 percent organic carbon, and 1.0 g/kg phosphorus. Biodeposits of filter feeders such as barnacles, tunicates, and other lamellibranchs were similar to those of oysters. Filter feeders may influence deposition, transport, and the composition of suspended sediments in estuaries. A possible relationship between the removal from suspension and the subsequent deposition of radio-nuclides associated with particles of clay, silt, or planktonic algae and feces or pseudofeces is suggested. (A.A.)

Keywords: oysters, invertebrate filter feeders, biodeposition, fecal pellets

III-F-5

Johannes, R.E., and M. Satomi. 1966. Composition and nutritive value of fecal pellets of a marine crustacean. *Limnology and Oceanography* 11:191-197.

The role of feces in energy flow and nutrient cycles in the marine ecosystem was examined using fecal pellets of the shrimp Palaemonetes pugio, fed on the diatom Nitzschia closterium. The pellets were rich in organic matter, particularly protein. The feces were readily eaten by P. pugio when diatoms were not available and assimilation efficiency was high, indicating that the pellets contained considerable assimilable organic matter. Solution and bacterial respiration reduced the organic

content of the feces, while light and dissolved organic matter stimulated the growth of autotrophic and heterotrophic microorganisms.

It is estimated that the rate of incorporation of organic matter into fecal pellets in the sea exceeds the rate of incorporation of organic matter into herbivore tissue and that fecal pellets therefore constitute a major potential food source for marine animals. (A.A.)

Keywords: nutritive value, fecal pellets, marine crustaceans, energy flow

IV. MARSH ESTUARIES AS FISH HAVENS

A. Estuarine Ecosystems

IV-A-1

McHugh, J.L. 1968. Are estuaries necessary? Commercial Fisheries Review 30(11):37-44.

The article is an excerpt from a talk presented by Dr. McHugh before the Annual Meeting of Sportmen's Clubs of Texas at Austin. Accordingly, the article is rather general and broad-based as to content; however, a considerable portion of the discussion centers on the importance of estuaries and the results of man's intrusions in these areas. The discussion is interlaced with specific examples of the necessities for estuary conservation. (L.H.)

Keywords: estuaries, general

IV-A-2

Tabb, D.C. 1965. Treasure those estuaries! Proceedings of the Gulf and Caribbean Fisheries Institute 18:47-50.

Until recently, the fisheries of coastal areas have been harvested annually, but man has given little thought as to how these fisheries came to be where they are, or what permits such abundance of valuable fish in such small areas of total ocean surface. The answer lies, to a great degree, in the fact that food of one sort or another is most abundant there. The reason food is so abundant is that estuaries, lagoons, and marshes are natural food traps. Not only do these areas trap food, but they also dispense it regularly and in abundance during the changing cycles of temperature, runoff, and sunlight intensity. If sea-farming ever becomes a reality, it will be because man will have become able to duplicate the productivity of the estuaries, not the open sea. Modern fishery management must take into account the role of the estuaries in production since conditions in estuaries as well as in the spawning grounds appear to govern abundance of a majority of fish and shellfish. (A.A.)

Keywords: estuaries, fisheries, food traps, productivity

IV-A-3

Rounsefell, G.A. 1963. Realism in the management of estuaries. Alabama Marine Resources Bulletin No. 1.

Estuaries are an important part of a complex ecosystem, which includes the vast area of the continental shelf, largely because

they are nursery areas for many species, including menhaden, shrimp, mullet, tarpon, and several sciaenids. The author states that recommendations for managing estuaries based on narrow aspects of the problem, without regard for the whole system, are a danger to important sport and commercial fisheries.

Too much emphasis is being placed on management based on primary productivity because "high primary productivity does not necessarily result in a high level of yield of the species desired by the sport and commercial fisherman." Recommendations for management must consider the life history and population dynamics of the species for which management is proposed. (B.W.)

Keywords: estuarine management, nursery areas, fisheries, primary productivity

IV-A-4

Cain, S.A. 1968. Estuaries: our most endangered natural habitats. Pages 41-48 in J.D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

Estuarine habitats are extremely productive areas, exceeding the production of ordinary agricultural land by one order of magnitude and that of deserts and deep oceans by two orders of magnitude. Constant enrichment by topsoil from the land and the stirring of bottom sediments by winds and tides makes estuarine waters a rich mix for bacteria, plant and animal plankton, shellfish, crustacea, insects, finfish, turtles, birds, and mammals.

Estuaries are an ecosystem, rather than a single habitat, and comprise numerous subsystems. Differences in bottom materials (mud, peat, sand), water depth, length of periods of submergence and emergence by the tides, currents and exposures to winds, and other factors influence the various communities in estuaries.

These areas are also commercially valuable as fishing towns, resort or recreation areas, industrial and trade centers, and transportation centers. The problem is not that estuarine regions have many and varied legitimate uses but that use must be carefully planned. Consideration must be given to the costs and benefits of the alternatives so that estuarine resources can be used to serve different needs, commercial or developed and natural.

The author suggests that cooperation among local and state governments, the Corps of Engineers, and the Department of the Interior will protect estuaries from destruction while allowing for maximum appropriate utilization. (B.W.)

Keywords: estuaries, habitats, productivity, marine ecosystems

IV-A-5

Day, J.W., Jr. 1973. Some trophic relationships of marsh and estuarine areas. Pages 115-135 in R.H. Chabreck, ed., Proceedings of the coastal marsh and estuary management symposium. Louisiana State University, Baton Rouge.

While true marine ecosystems are usually based on a phytoplankton energy source, estuaries usually have a more diverse group of primary producers which allows a more complex structure and much higher production and average standing crop biomass at all trophic levels. The most striking single difference in estuarine systems is the fact that some contain emergent vascular plants that utilize atmospheric carbon and oxygen directly without the limitations placed on utilization of these materials in aquatic systems. This results in a higher order of production within estuaries that have important amounts of marsh or mangrove swamp as components of the system. The production from emergent plants is the source of most detrital material that gives the familiar detrital-based structure to estuarine food chains. Detritus is also often abundant in estuaries from exogenous sources, particularly larger rivers that carry organic matter from inland drainage basins into the system.

Important factors in the trophic relationships are: (1) Organic detritus; (2) tides and other currents for moving organisms, food and other materials; back-and-forth movement of the tide superimposed on river currents, a characteristic of most estuaries; and (3) the large number of seasonal (and daily) migrants. Many organisms use the estuary at times when food is abundant and during fast growing stages of their life cycle. More sensitive times of the life cycle are spent under stable conditions, often offshore.

Overall estuarine productivity will be maximum when: (1) The estuary is formed by a major river system; (2) it is located in or near the subtropical zone; (3) it is situated on a wide, shallow continental shelf so that there is a large area of intertidal land; (4) the drainage basin of the river system is an old geologic province and is large compared to the estuarine area. Large volumes of suspended materials, nutrients, and detritus will be carried to the estuary; (5) the climate of the drainage basin as well as the estuary is not arid; and (6) there is a low to moderate coastal energy regime. (G.S.)

Keywords: trophic relationships, coastal marshes, estuarine areas, primary productivity, mangroves, U.S. general

IV-A-6

American Fisheries Society. 1966. A symposium on estuarine fisheries. Special Publication No. 3, Washington, D.C. 154 pp.

This book is a collection of papers developed from talks given on estuarine fisheries and associated problems during a symposium sponsored by the American Fisheries Society. Concern for estuarine fishery resources stems largely from the fact that at least 65 percent of U.S. commercial fish and shellfish and most marine sport species inhabit the estuarine environment during all or part of their life cycle. The contribution of these estuarine fishery resources to our general health and economic well-being has increased at a far greater rate than was predicted. For most estuarine fishery resources, the major problem will be to provide an adequate supply in the face of increased demands and dwindling habitat.

The estuarine environment is complex. Generalists who recognize man as an important member of the ecosystem and specialists from a variety of disciplines are needed to develop solutions to many estuarine problems. Five of the papers from this book have been selected for review in this bibliography. (See IV-A-7, IV-E-12, IV-E-16, IV-E-31, and IV-E-34.) (J.B.)

Keywords: fisheries, estuarine community, U.S. general

IV-A-7

McHugh, J.L. 1966. Management of estuarine fisheries. Pages 133-154 in American Fisheries Society, A symposium on estuarine fisheries. Washington, D.C.

Almost two-thirds (by value) of the United States commercial catch and much of the marine sport catch is composed of species that spend at least a part of their lives within estuaries. Dominance of estuarine species is especially great in catches along the Atlantic and Gulf coasts. Invertebrates are important in the commercial catch in these regions also, accounting for considerably more than 50 percent of the value of landings from Chesapeake Bay south and in the Gulf of Mexico.

Estuarine fishery resources inhabit a rich but stressful environment. Man's increasing fishing pressures and his other modifications of the environment place additional stresses on the resources, and man's diverse interests in the resources and their environment create difficult social-political problems. Many of the methods of dealing with these problems are antiquated and inefficient, and scientific knowledge is seldom adequate to provide clear-cut answers. The complex life-histories of most estuarine fishery resources require unusually detailed knowledge of ecology as a basis for management. Seldom have we had the facilities and resources to obtain such knowledge, and this is one reason why virtually none of our estuarine fishery resources is under effective

scientific management to produce maximum sustainable yields. Solution of these problems will require improved public understanding, increased support, coordination of research and management programs, and greater opportunity for calm discussion and compromise. (A.A.)

Keywords: commercial fishes, estuarine management, fisheries, Chesapeake Bay, U.S. Gulf coast

IV-A-8

Douglas, P.A., and R.H. Stroud, eds. 1971. A symposium on the biological significance of estuaries. Sport Fishing Institute, Washington, D.C. 111 pp.

This publication is a product of a one-day scientific Symposium on the Biological Significance of Estuaries, which was held in 1970 and co-sponsored by the Sport Fishing Institute and the National Wildlife Federation. The symposium was designed to inform laymen, in terms they could understand, in what ways the estuaries of the United States are important and how they can be maintained for many uses.

More than half of the marine fisheries resources of the Continental Shelf adjacent to the U.S. land mass is fully dependent upon estuaries as spawning and/or nursery areas. Estuaries are also critical links in upstream and downstream migration routes of fishes. This symposium was held in an attempt to improve the public comprehension needed to create an improved climate for solving the problems of maintaining the estuarine environment in a productive condition.

Chapters are included on the biology of the estuary, the Texas water plan and its effect on estuaries, the effect of water development on striped bass in the Sacramento-San Joaquin estuary, the biological effects of estuaries on shellfish of the Middle Atlantic, the effects of pollution on estuaries of the Northwest Pacific coast, and the significance of an estuary on the biology of aquatic organisms. Some of these chapters are reviewed elsewhere in this publication. (See IV-B-8, IV-C-8, and IV-E-30.) (B.W.)

Keywords: estuaries, fisheries resources, productivity, U.S. coastal regions

B. Estuarine Fauna

IV-B-1

Perkins, E.J. 1974. The biology of estuaries and coastal waters. Academic Press, New York. 678 pp.

This is a comprehensive treatise on coastal and estuarine waters and their faunal inhabitants. Scattered comments are made on the role of marshlands in nutrient production and as habitat for various organisms. Food-web diagrams are provided. (J.B.)

Keywords: estuaries, nutrient production, food web

IV-B-2

Barnes, R.S. 1974. Estuarine biology. Edward Arnold, London. 76 pp.

Four chapters of this book are relevant to invertebrates and higher forms of life. Chapter 4 considers adaptations of mudflat animals in the variable and rigorous intertidal areas. Included are: (1) anatomical specializations for feeding, gaseous exchange, and vision; (2) physiological specializations; and (3) behavioral specializations.

Two sections of chapter 5, reclamation of intertidal areas and uses of estuaries, are relevant to the productivity of estuarine areas. Although reclamation tends to destroy existing aquatic habitats, its main effects are seen as being felt by migratory estuarine birds. Many commercially important estuarine animal species spend at least part of their life cycles there. Estuaries are areas of abundant food supply, much of it unconsumed by resident species; thus, it is used by a large number of fish as a nursery area. Estuaries are also important to birds that feed on fish, and to shellfish, mussels, oysters, and similar invertebrates. Recreational fishing, valued in the millions of dollars for Texas and other coastal states, is also a reflection of their overall importance.

Studies of estuaries involved field studies of distribution and abundance, observations of animal behavior, and laboratory studies. Other brackish waters are discussed by type as they occur on a worldwide basis. (G.S.)

Keywords: invertebrates, mudflat animals, estuaries, productivity

IV-B-3

Green, J. 1968. The biology of estuarine animals. University of Washington Press, Seattle. 401 pp.

This book provides an overview of the biology of animals living in estuaries. A broad concept of an estuary is adopted so that the animals dwelling in brackish seas can also be considered.

The book is divided into the following sections: structure and dynamics of estuaries; salinity and other chemical factors; estuarine vegetation; introduction to estuarine faunas; estuarine plankton; estuarine macrobenthos; estuarine microbenthos; the freshwater component; the terrestrial component; estuarine fishes; estuarine birds; estuarine parasites and epibionts; and estuarine food webs. (H.D.)

Keywords: estuarine animals, estuaries, food web

IV-B-4

Vernberg, W.B., and F.J. Vernberg. 1972. Environmental physiology of marine animals. Springer-Verlag, New York. 346 pp.

The book emphasizes the environmental physiology of the marine fauna representing the intertidal zone, estuaries, coastal and oceanic waters, and the benthic regions. The responses of organisms to various ecological factors are examined. Tolerant physiology, as influenced by such factors as temperature, salinity, oxygen, and pollutants, is discussed.

Chapters on the intertidal zone, the estuarine environment, and the coastal and oceanic environment include introductions and discussions of resistance adaptations and capacity adaptations. A list of references follows each chapter. (B.W.)

Keywords: marine animals, estuarine areas, intertidal areas

IV-B-5

Reid, G.K. 1961. Ecology of inland waters and estuaries. Reinhold Publishing Corporation, New York. 375 pp.

The book is an introduction to the elemental factors and processes that operate in lakes, streams, and estuaries as dynamic systems. Major aspects of the knowledge that has been amassed from the study of inland waters and estuaries are summarized. Principles are emphasized rather than detailed information.

Estuaries are discussed in terms of origin, morphology of estuarine basins, modification of original estuaries, parameters of estuarine

basins, and estuarine shores and substrates. Thermal properties of estuaries are discussed, as well as the animal inhabitants of inland waters and estuaries.

Other areas discussed include: lakes, streams, solar radiation, natural waters in motion, gases, dissolved solids, protists and plants, and aquatic communities. (H.D.)

Keywords: ecology, estuaries, estuarine characteristics

IV-B-6

McHugh, J.L. 1967. Estuarine nekton. Pages 581-620 in G.H. Lauff, ed., Estuaries. American Association for the Advancement of Science, Washington, D.C.

Estuarine nekton is discussed in general terms with sections on the nektonic estuary, adaptations for nektonic existence, the estuarine environment, distribution and abundance of estuarine nekton, food cycles and energy exchange, the estuarine nekton, fisheries for estuarine nekton, and man and estuarine nekton.

The author states that although the nektonic species of the Chesapeake Bay and the Gulf of Mexico may have spent important parts of their lives in enclosed estuarine waters, their entire biomass cannot be attributed to weight added in the inshore estuary. In both regions commercial fishery yields probably should be attributed to areas broader than the area of the inshore estuaries, and the yield per acre should be adjusted downward accordingly.

The conclusion drawn by the author is that the standing crop or annual production in numbers and biomass of nekton in any estuary cannot be stated. Attempts to compute the annual production of nekton in the inshore estuary will not produce realistic results, because most members of the estuarine nekton move freely between the inshore and the offshore estuarine environment. (B.W.)

Keywords: estuaries, fishes, food ecology, productivity, biomass, Chesapeake Bay, U.S. Gulf coast

IV-B-7

Sewell, G.H., and R.F. Hillman. 1971. The future economic value of estuarine-dependent commercial fisheries, Appendix B, pages B-1 through B-22 in The economic and social importance of estuaries. Estuarine Pollution Study Series No. 2. U.S. Environmental Protection Agency, U.S. Government Printing Office, Washington, D. C.

The author states that U.S. fishermen received approximately \$438 million for about 4.06 billion pounds of commercial fish and

shellfish in 1967. Two-thirds of this total value, or approximately \$300 million, can be considered derived from estuarine-dependent species.

The future economic value of the estuarine-dependent species for the U.S. commercial fishing industry will depend upon three major forces influencing trends: (1) The shifting market demand for fishery products in the U.S.; (2) the state of the commercial fishing industry on a world-wide basis; and (3) the compatibility between evolving conditions in the U.S. estuaries and the production of adequate fishery stocks.

The author discusses market demand for fish products including industrial and edible fish products. Trends in the world fisheries in relation to production costs and world demand is also covered.

Estuarine-dependent species are divided and discussed in four groups: (1) truly estuarine species, (2) anadromous and catadromous species, (3) seasonally estuarine species, and (4) marine species using estuaries as a nursery.

Estuarine dependence of shrimp, menhaden, and oysters is also discussed in detail. (H.D.)

Keywords: estuaries, commercial fishes, nursery areas, fisheries resources, U.S. coastal regions

IV-B-8

Cronin, L.E., and A.J. Mansueti. 1971. The biology of the estuary. Pages 14-39 in P.A. Douglas and R.H. Stroud, eds., A symposium on the biological significance of estuaries. Sport Fishing Institute, Washington, D.C.

Estuaries are defined as semi-enclosed bodies of water that have free connections with the open sea and within which sea water is measurably diluted by fresh water from land drainage. The nearly 900 estuaries along the coasts of the United States vary considerably.

Some physical, chemical, and geological characteristics of estuaries are discussed, including those characteristics that appear to be common to many estuaries. Salinity, river flow, tidal movements, and the chemical activity of elements and compounds are mentioned.

The biological patterns of estuaries are discussed in detail: bacteria, phytoplankton, zooplankton, benthos, and fishes. Fishes, in particular, use estuarine waters in any or all of these ways--as spawning grounds, nursery area, or feeding grounds.

Population expansion and migration and technological development have placed additional stress on many estuaries. The authors encourage rational and effective efforts to live in harmony with the complex and sensitive ecosystems of these valuable but fragile areas. (B.W.)

Keywords: estuaries, aquatic ecosystems, bacteria, phytoplankton, zooplankton, fishes, U.S. coastal regions

C. Area Studies

IV-C-1

Caillouet, C.W. 1970. Commercial and recreational fishery resources of estuarine waters, southern United States. Pages 44-48 in W.G. Weist, Jr., ed., Hydrobiology. American Water Resources Association.

The report briefly examines the relationship between the most important commercial and recreational fishery resources and the estuarine environment of the southern states. These states include the coastal states of Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, and North Carolina.

Gunter estimated that nearly 98 percent of the commercial catch of the Gulf States is made up of estuarine species. Most motile estuarine animals of the Gulf Coast have similar life histories. Adults spawn in the Gulf and larvae make their way into the estuaries. The young develop in the estuaries and return to the sea. The American oyster will apparently live and reproduce at seawater salinities, but it grows, lives, and reproduces best under estuarine conditions. The shrimp resource is also dependent on the estuaries, which provide nursery areas and sometimes support adult populations.

Odum found that the principal source of food for the aquatic animal community is vascular plant detritus originating primarily from red mangrove leaves. Certain omnivorous estuarine organisms ingest detritus forming a link between detritus production and production of higher consumers. Both commercial and sport fishes utilize this intermediate group of omnivores as food. The most valuable commercial species, Penaeus spp. shrimp, ingest the detritus directly. (B.W.)

Keywords: fishery resources, estuarine areas, detritus, U.S. South Atlantic and Gulf coasts

IV-C-2

Cottam, C. 1968. Research needs in estuarine areas of the Gulf Coast. Pages 227-240 in J. D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

Much of the food for fin and shellfish and shrimp, as well as for their respective food chains, found in the more permanent waters of estuaries originated in the adjacent marshes, tidal flats, and periodically flooded semi-upland areas. Food chain interrelationships need more research.

Better management of estuaries is needed if they are to be protected. To accomplish this, knowledge of the overall ecological relationships of total communities of organisms is needed. This study should include waterfowl, mammals, grasses, amphibians, and fishes, among others. Effects of dredging and filling and changes resulting from pollution need to be examined.

Fully two-thirds of all coastal sport fish are dependent on estuaries during all or a part of their lives. More research is needed not only on the biological and ecological aspects of the species but also on the different types of environment. A major need is a broad study of the ecology of the Gulf and its estuaries and an understanding of the physical conditions that produce and maintain estuaries. (B.W.)

Keywords: estuaries, shellfish, shrimp, food chains, U.S. Gulf coast

IV-C-3

Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. Pages 621-637 in G.H. Lauff, ed., Estuaries. American Association for the Advancement of Science, Washington, D.C.

In recent years, the total production of fisheries along the 1,500 miles of Gulf coast represents about 28 percent of the U.S. total. The 425 miles of coast between Pascagoula, Mississippi, and Port Arthur, Texas, accounted for 21 percent of total U.S. fishery products. This region has been called the "Fertile Fisheries Crescent."

In 1961 the order of rank of species in terms of weight was: menhaden, one billion pounds; brown shrimp, 39 million pounds; croakers, 39 million pounds; blue crabs, 35 million pounds; striped mullet, 33 million pounds; pink shrimp, 24 million pounds; flat croakers, 18.5 million pounds; oysters, 18.2 million pounds; and white shrimp, 14 million pounds.

During 1961, fishery production in the Gulf states amounted to 1,377 billion pounds, of which 9.3 million pounds came from fresh

water. The catch of those fishes which have little or no connection with estuaries amounted to 24.4 million pounds, while the catch of estuarine species amounted to 1,332 billion pounds, including oysters and crustaceans. In short, estuarine species make up about 97.5 percent of the total commercial fisheries catch in the Gulf states; saltwater species, about 2.0 percent; and freshwater species, about 0.5 percent.

The general life histories of most of the motile estuarine animals along the Gulf coast follow a similar pattern. The eggs are spawned at sea and the larvae somehow make their way into the low-salinity waters of the estuaries. The young animals develop in the estuaries and then return to or towards the sea. The author relates the salinity factor, populations, and fertility to distributions of estuarine organisms. (H.D.)

Keywords: estuaries, fisheries, estuarine animals, life histories, U.S. Gulf coast

IV-C-4

Walford, L. 1968. Values of the South Atlantic and Gulf coast marshes and estuaries to sport fishery resources. Pages 79-82 in J.D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

Only a few species of fish can be categorized exclusively as sport fish and even those are not totally exempt from being caught by commercial fishermen. Consequently, there are no properties in the estuarine zone that have values for sport fishes different from those affecting other species. The importance of sport fishing to conservation agencies and others lies in the fact that during the past twenty years sport fishing has grown into a very popular form of recreation and an important industry in terms of economics. Two values of estuaries to fishery resources are presented: (1) estuaries provide an enormous area of shallow water habitat; (2) there are many estuaries along the Atlantic and Gulf coasts. (B.W.)

Keywords: coastal marshes, estuaries, sport fisheries, U.S. South Atlantic and Gulf coasts

IV-C-5

Copeland, B.J., and T.J. Bechtel. 1974. Some environmental limits of six Gulf coast estuarine organisms. University of Texas Contributions in Marine Science 18:169-204.

Literature and data analysis of six sports and commercially important species occupying Gulf coast estuaries were made utilizing a computerized

sorting technique. Data relating to catch versus environmental characteristics were collated from literature references and the data files of several state and federal laboratories. Catch ratios, reflecting catches above a threshold value, were computed and sorted into temperature, salinity, seasonal and location classes and into various interaction categories.

Gross temperature, salinity, location and season ranges and optima were established for menhaden (Brevoortia patronus), sand trout (Cynoscion arenarius), blue crabs (Callinectes sapidus), and white shrimp (Penaeus setiferus), pink shrimp (Penaeus duorarum) and brown shrimp (Penaeus aztecus). Analyses of interactions among the environmental variables verified several conclusions from single factor analyses, but also delineated many details of habitat, migration and estuarine utilization.

The technique developed is considered to be capable of describing outside limits and providing management criteria for estuarine programs. (A.A.)

Keywords: estuarine organisms, fisheries, menhaden, sand trout, blue crabs, white shrimp, U.S. Gulf coast

IV-C-6

Sykes, J.E. 1968. Commercial values of estuarine-generated fisheries on the South Atlantic and Gulf of Mexico coasts. Pages 71-78 in J.D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

The significance of estuaries in perpetuating portions of the marine resource has been proved; and available information shows that, depending upon geographical area, 65 to 90 percent of the commercial catch of finfish in the United States consists of estuarine-dependent species. Clupeoid fishes caught in the United States are estuarine-dependent and are harvested largely for their value as protein supplement in diets of domestic animals. The usefulness of the coastal zone to man will be more accurately seen when the unrealized potential of these fishes is developed.

Research scientists are convinced that estuaries are essential to fish production and deserve more careful attention than they have received in the past. Solutions to estuarine management problems have not been developed because scientific programs have not generally adopted common goals and the attention to estuarine ecological research is too new to have become maximally effective. (A.A. and B.W.)

Keywords: estuaries, fisheries, productivity, U.S. South Atlantic and Gulf coasts

IV-C-7

Massachusetts Department of Natural Resources. Undated. Estuarine research program. Division of Marine Fisheries Monograph Series. Not numbered.

The estuarine research program in Massachusetts was initiated in 1963 as the result of recommendations by the Marine Fisheries Advisory Commission to the Governor of the Commonwealth. The Commission recognized the value of the marine resources of the Commonwealth and the urgent need for pertinent information which would lead to the establishment of a sound resource management program.

Studies were conducted on several estuarine communities in Massachusetts. The monograph series represents the findings and recommendations resulting from these investigations. Each report contains a chapter on marine vegetation and its value to the estuarine community. (H.D.)

Keywords: estuarine research, marine resources, Massachusetts

IV-C-8

Massman, W.H. 1971. The significance of an estuary on the biology of aquatic organisms of the middle Atlantic region. Pages 96-109 in P.A. Douglas and R.H. Stroud, eds., A symposium on the biological significance of estuaries. Sport Fishing Institute, Washington, D.C.

The mid-Atlantic coast from Cape Cod to Cape Hatteras includes a number of estuaries. The largest, most varied, and most important for aquatic organisms is the Chesapeake Bay. The marshes and swamps bordering the Chesapeake and its tributary streams are extremely important components of the estuarine complex. Roughly one-third of a million acres of salt marsh habitat surround the bay.

Biologically, the estuary is a very productive area. The annual fish harvest from the Bay, both sport and commercial, amounts to about 125 pounds per acre. In addition to yielding some 325 million pounds of finfish to Bay fishermen, the Bay serves as a nursery area for other fish caught in areas from Maine to North Carolina. For the entire Atlantic coast, 19 different kinds of commercial fish are directly dependent on estuaries.

Not all aquatic life in the Chesapeake is economically desirable or beneficial to man. Jellyfish, ctenophores, shipworms, barnacles, oyster drills, saltmarsh mosquitoes, and green-headed flies are all destructive or annoying to man.

Waterfowl, shorebirds, other aquatic birds, and aquatic mammals are closely associated with the Chesapeake and its marshlands. The area also supports populations of muskrat, mink, raccoon, otter, and porpoise.

Changes in the estuary that would reduce freshwater inflow, such as dredging and filling or the introduction of various kinds of pollutants, all influence the estuary in a variety of ways. A thorough knowledge of the relationships of the physical, chemical, and biological factors will enable people to avoid changes that will be most harmful, minimize the destructive effects of some changes, and even improve the estuary for production of desirable aquatic life. (B.W.)

Keywords: estuaries, aquatic ecosystems, productivity, fisheries resources, estuarine animals, environmental change, U.S. Atlantic coast

IV-C-9

Wass, M.L., and T.D. Wright. 1969. Coastal wetlands of Virginia, interim report. Special Report in Applied Marine Science and Ocean Engineering No. 10. Virginia Institute of Marine Science, Gloucester Point. 154 pp.

Coastal wetlands occupy only 1 percent of the total area of Virginia and marshes occupy 1/2 percent. Yet 95 percent of Virginia's annual harvest of fish, both commercial and sport, from tidal waters is dependent to some degree on wetlands.

Wetland productivity ranges from very little on some small salt barrens to about 10 tons per acre per year in the best grass marshes. Productivity on the tidal flats, which apparently cover more area than does marsh on the eastern shore seaside, is probably at least one-fourth that in the marsh. Virginia has not yet adopted a legal definition of wetlands. Such a definition is needed before protective legislation can be enacted.

Preliminary economic evaluation of wetland productivity indicates that an average acre of wetland generates primary tangible benefits of \$78 per year. These benefits largely accrue to the public rather than to the wetland owner. Present wetland use and management is determined by the owner and often does not constitute the most beneficial use of the land to the public. To insure continuing high yields, to enhance value, and to serve the best public interests, it is recommended that the state acquire or otherwise exercise some degree of control over the uses and alterations of wetlands. (A.A.)

Keywords: coastal marsh, freshwater swamps, productivity, planning and management, Virginia

D. Site Studies

IV-D-1

Hedgpeth, J.W. 1967. Ecological aspects of the Laguna Madre, a hypersaline estuary. Pages 408-419 in G.H. Lauff, ed., Estuaries. American Association for the Advancement of Science, Washington, D.C.

The Laguna Madre of Texas is a series of coastal lagoons, consisting of a long narrow outer lagoon separated from the Gulf of Mexico by Padre Island, and divided into northern and southern parts by extensive, barren flats, and an inner tributary, Baffin Bay, extending westward like an elbow from the lower part of the main Laguna.

There is an abundant and varied fish fauna in the various parts of the Laguna. Among the resident species in the Laguna Madre are the tenpounder or skipjack (Elops saurus), anchovies (Anchoa spp.), three species of cyprinodontids (Fundulus similis, F. grandis, and Cyprinodon variegatus), the silversides (Menidia beryllina peninsulae), mullet (Mugil cephalus), the spotted sea trout (Cynoscion nebulosus), and the black drum (Pogonias cromis). These species are known to spawn in the Laguna, and most of them are winter or early spring spawners. While complete data are lacking, it appears that most of these species do not spawn in concentrations of salinity in excess of 45 parts per thousand (ppt). Some of them, however, probably spawn in higher salinities; an atherinid (Atherinops affinis affinis) can spawn in concentrations of 72 ppt, but the young die within four months. Many other species of fish spend considerable time in the Laguna, but do not spawn there and usually leave in summer during temperature and salinity rises. Other fish are occasional visitors. More than 70 species of fishes occur in the upper Laguna Madre. Two of the most important species in terms of species mass and representation in both sports and commercial fisheries are the redfish, Sciaenops ocellata, and the black drum, Pogonias cromis. The redfish is not a permanent resident, and does not spawn in the Laguna, while the black drum does. The black drum also seems to withstand higher temperatures and salinities, although older fish tend to become deformed and blind in the highest salinities.

The living invertebrates of the Laguna have not been so thoroughly studied as the fishes. Crustaceans of several species are abundant, and make up a significant part of the food for several species of fishes, especially the redfish. Young blue crab, Callinectes sapidus, and the small mud crab, Neopanope texana, are the important crabs. Young penaeids, especially Penaeus aztecus, and the small resident grass shrimp, Palaemonetes intermedius, are the most important shrimp. Acartia tonsa is apparently the dominant copepod of the Laguna waters, and feeds on some reddish submicroscopic plankters. It is important as a food item for small fish.

Several small bivalves are common in various parts of the Laguna, and constitute a major element in the diet of the black drum. The most common species are Anomalocardia cuneimeris and Mulinia lateralis; evidently these occur in extensive beds although there is no clear information on the locations of these beds or the density of molluscs per unit area.

In the Laguna Madre there are at least 25 species of animals that persist or withstand concentrations of 75-80 ppt salinity. Some of these also occur in salinities as low as 15 ppt. Data are provided showing the occurrence of certain metazoa in salinities of 45 ppt and above. (H.D.)

Keywords: estuaries, salinity, fish, invertebrates, Texas

IV-D-2

Hellier, T.R. 1962. Fish production and biomass studies in relation to photosynthesis in the Laguna Madre of Texas. Publications of the Institute of Marine Science, University of Texas 8:1-22.

The rate of growth of populations of animal consumers depends to a considerable extent on the rate of food supply derived from photosynthetic production of plant material either within or imported into the community. Yet few studies directly relate fish production to plant production. In the present study, an effort has been made to relate fish production to gross plant production in a shallow, frequently hypersaline coastal bay, the Upper Laguna Madre of Texas. The Upper Laguna Madre is located on the Texas Gulf Coast immediately south of Corpus Christi Bay, and is separated from the Gulf of Mexico by a narrow barrier island, Padre Island.

The northern portion of the bay is very shallow, ranging from one to three feet deep in the zone extending for 13 miles south of the causeway, where there is a natural basin approximately five feet deep. This basin delimits the southern boundary of the present study area. The shallow portion of the Upper Laguna Madre was covered with a dense growth of shoalgrass (Diplanthera wrightii) and widgeongrass (Ruppia maritima). Acetabularia crenulata was frequently encountered in the area, though it was never abundant.

Biomass estimates of the animal species present were determined with a new population sampling device, the drop-net quadrat. The principle of this method is to isolate instantaneously a segment of the study area with its natural fish population, and by extrapolation determine the approximate density of the fish population of the area. Twenty-nine samples were taken over a 17-month period from March 1958 to August 1959.

Age and growth estimates of the dominant fish species were determined by scale analysis, and by reference to length frequency histograms. A total of 31 species were taken during the study, five of which constituted approximately 70 percent of the biomass. These five species were Mugil cephalus, Lagodon rhomboides, Leiostomus xanthurus, Anchoa mitchilli, and Menidia beryllina.

Fish production as used in this paper was defined as the weight increase of the fish per unit time while the fish were in the study area. The monthly weight increases for all of the individuals collected during each month were totaled and placed on a per acre basis. Primary gross plant production was measured by the diurnal oxygen method with oxygen samples taken every three hours over a 24-hour period.

Biomass estimates of fish and larger invertebrates ranged from a summer maximum of 337 pounds per acre (37.8 g/m^2) to a winter minimum of 18 pounds per acre (2.0 g/m^2). The annual fish production estimate was 137 pounds per acre (15.4 g/m^2 dry weight) as compared with an annual gross primary plant production estimate of $4177 \text{ g/m}^2/\text{yr}$ expressed as oxygen. The seasonal migration and growth of fish stocks are in phase with the primary production of food. (A.A.-modified)

Keywords: fish production, photosynthesis, biomass, Texas

IV-D-3

Gunter, G. 1950. Distributions and abundance of fishes on the Aransas National Wildlife Refuge, with life history notes. Publications of the Institute of Marine Science, University of Texas 1:89-101.

This paper reports findings of a study on the fish fauna of the marginal ponds and salt flats of the Aransas National Wildlife Refuge on the Texas coast. Life histories for ten fish species are provided.

The family Cyprinodontidae made up 28.5 percent of the fishes caught on the bay shore, 67 percent of those taken in salt flat ponds, and 79.3 percent of those taken in the freshwater ponds. When all pond stations on the Refuge are considered, the Cyprinodontidae made up 74.9 percent of the catch.

In the small pond environment where they are subjected to great extremes of heat, cold, salinity and probably lack of oxygen, the Cyprinodontidae are the most common fish. The ability of this group, known as killifishes, to withstand adverse environmental conditions is well-known.

As the salinity gradient declines from the open sea to the river mouths, the number of species of fishes decline. The data presented indicate that from the bay shores to the freshwater ponds

farthest from the bay the numbers of species decline. Twenty-nine species were caught on the bay, seventeen on the salt flats, eight in freshwater ponds having had previous connections with the bay, and four in an isolated freshwater pond. (H.D.)

Keywords: fishes, life history, killifishes, salinity, Texas coast

IV-D-4

Parker, J.C., H.W. Holcomb, W.G. Klussman, and J.C. McNeill. 1971. Distribution of aquatic macro-fauna in a marsh on West Galveston Bay, Texas, and possible effects thereon resulting from impoundments for shrimp culture. Texas A & M University, Sea Grant Publication No. TAMU-SG-71-208. 38 pp.

A survey was conducted to identify the macro-fauna of a marsh adjacent to West Galveston Bay. The factors affecting their distribution were studied to help evaluate changes that might result in the event that large areas of the marsh were impounded for shrimp culture.

As a result of frequent tidal floods, saline conditions generally prevailed within the marsh. Freshwater floods resulting from local rainfall were common, but salt leached from the bottom sediments, coupled with subsequent tidal floods, readily re-established saline conditions.

The fauna consisted of a variety of marine and estuarine species. Those species that were abundant throughout the year and constituted the stable macro-fauna were Cyprinodon variegatus, Fundulus grandis, Poecilia latipinna, Mugil cephalus, Menidia beryllina, Palaemonetes sp., and Callinectes sapidus. These are among the hardiest of coastal aquatic animals and exhibited broad temperature and salinity tolerances.

Marine-dependent species were able to enter the marsh during tidal floods and many were trapped when waters receded. Post-larvae of some of these species were able to invade the marsh at normal tide level through narrow, vegetation-clogged ditches leading inland from the bay. Conditions were seldom favorable, however, for the return of marine species to the bay. They usually died as a result of low temperatures during the winter or drought conditions during the summer. These species generally disappeared from the marsh following freshwater floods and it was assumed that they were either forced out into the bay or died as a result of the rapid salinity decline which typically occurred.

Construction of large-scale impoundments for shrimp culture, at the expense of removing flooded grasslands, would alter the physical features of the marsh and reduce habitat suitable for year-round survival of the stable macro-fauna. In addition, competitor and predator control in these ponds would require the removal of all aquatic

macro-fauna other than shrimp. The impact of these changes on the total marsh ecosystem is not known but should be considered and studied in detail before ponds are constructed. Conceivably, marsh areas could be managed so as to insure a reasonable amount of habitat for the stable macro-fauna while allowing ample lands for shrimp culture. This could best be accomplished by restricting shrimp culture practices to open water areas, thus avoiding the removal of flooded grasslands. In addition, the pond flumes could be opened to the surrounding marsh during the winter months when temperatures are too low for shrimp culture, allowing the impounded areas to return to a more or less natural state. (A.A.)

Keywords: coastal marsh, macro-fauna, shrimp, Texas, Galveston Bay

IV-D-5

Conner, J.V., and F.M. Truesdale. 1973. Ecological implications of a freshwater impoundment in a low-salinity marsh. Pages 259-276 in R.H. Chabreck, ed., Proceedings of the coastal marsh and estuary management symposium. Louisiana State University, Baton Rouge.

A three-year study of a low-salinity marsh area in the Galveston Bay System of Texas revealed that certain of the marsh waters were prime habitat for the post-larvae and/or juveniles of several marine crustaceans and fishes, including commercial shrimps, Gulf menhaden, Atlantic croakers, sand seatrout, and southern flounder. Results of this and other investigations indicated that shallow, turbid, soft-bottomed lakes and blind bayous in the interior of marsh areas are the "target" habitats of many migrating young marine animals. Comparative catches per effort using the same gear in various portions of the Galveston estuary show, in general, that peripheral marsh waters can be much more productive per unit area than the more expansive open waters of the bays. There are further indications that brackish marshes associated with the upper estuary are more productive for some species than higher-salinity marshes of the lower bays. Therefore, a 7,200-acre section to be impounded in the Trinity River Delta, Chambers County, Texas, cannot be regarded as roughly equivalent in importance as "nursery habitat" as any other 7,200-acre area in the Galveston Bay System. The inability to make reliable estimates of the absolute value of a given estuarine habitat has been invoked as ground for disregarding possible losses to the commercial fisheries. If special habitat types within an estuary are to be protected from destruction, biologists must devise methods for estimating the absolute values of such habitats in terms of their ultimate contribution to fisheries harvests. (A.A.)

Keywords: low-salinity marsh, marine animals, productivity, Texas

IV-D-6

Loesch, H. 1971. Some observations on amounts of nanoplankton, nematodes, copepods, fish, and shrimp found in the Barataria Bay Area, Louisiana. Louisiana State University, Coastal Studies Bulletin No. 6, Special Sea Grant Issue, pp. 38-44.

Seasonal biomass estimates were made of nanoplankton, nematodes, copepods, shrimp, and fish in the Barataria Bay area by using quantitative and non-quantitative data assembled by various investigators. Some assumptions were necessary in estimating the biomass of each group of animals per unit area for seasonal or monthly periods. All measurements are reported in grams per square meter of either bottom area or water column. (A.A.)

Keywords: nanoplankton, nematodes, copepods, fish, shrimp, Louisiana

IV-D-7

Mulkana, M.S. 1966. The growth and feeding habits of juvenile fishes in two Rhode Island estuaries. Gulf Research Reports 2:97-168.

The purpose of this work was to evaluate selected Rhode Island estuaries as nursery grounds for juvenile fishes. The juvenile stage in the life history of fishes follows the emergence from larval life to an independent young phase. At this stage survival becomes dependent on physiological and morphological fitness, availability of suitable types of food, and protective adaptations to minimize predator and parasite invasion and overpopulation pressure. The immature young of coastal and offshore fishes of many species spend their critical juvenile period in protected, food-rich estuaries. Often the success of stocks in a fishery is dependent on the presence of areas suitable as nursery.

Greely, Warfel and Merriman, and Percy and Rickards, who studied the seasonal variations and ecology of juvenile and adult fishes along the New England coast, and Shuster who conducted similar investigation in Delaware Bay estuaries, all reported a great abundance of fish-of-the-year of various species in the shallow waters of coastal ponds, estuaries, and bays. Fish's observations in Rhode Island waters point to the same conclusions. Information from all of these sources provides strong evidence that estuarine environments play a vital role in the survival and maintenance of stocks of the coastal and offshore fisheries of commercial significance. (Author's introduction, modified)

Keywords: fish, estuaries, nursery grounds, Rhode Island

IV-D-8

Saila, S.B., and S.D. Pratt. 1973. Mid-Atlantic Bight fisheries. Pages 6-1 through 6-125 in S.B. Saila, ed., Coastal and offshore environmental inventory: Cape Hatteras to Nantucket Shoals. Marine Publication Series No. 2, University of Rhode Island, Kingston.

In the Mid-Atlantic Bight, Chesapeake Bay has a considerable influence on the fisheries of the entire area.

During recent years an estimated 27,000 commercial fishermen have harvested annually about 700 million pounds of fish and shellfish, valued at roughly 70 million dollars, in the study area. An analysis of the value and volume landed during a five-year period showed considerable stability among the more important species with only minor exceptions. Of the several hundred species of fish and shellfish found in the region, only about 30 are of significant commercial value at present. The full commercial fisheries potential for this region has not yet been realized. Although some species are heavily exploited or overexploited, a few species still remain unutilized.

The significance of estuaries and shallow coastal waters is very great in this region. This is demonstrated by the fact that shellfish and certain estuarine-dependent fishes rank very high in terms of both value and volume in the annual commercial harvest.

Sport fishing in the Mid-Atlantic Bight area is rapidly increasing in popularity. An estimated 2.5 million salt-water anglers generated more than 318 million dollars of business activity in 1970. This region is expected to be able to absorb considerably more sport fishing activity without major conflicts with other users and with negligible reductions in the catch.

Although current use of the Mid-Atlantic Bight is minimal for mariculture, this use is expected to increase. Future developments are expected to occur in the culture of organisms with relatively high market value. Oyster culture is expected to expand in areas such as Chesapeake Bay and Long Island Sound. The possibility of using heated effluents from electric power generating stations in this region merits further study.

Detailed fisheries investigations are requisite to responsible long-term management of commercially or recreationally important species. The nature of these investigations has been briefly described, and specific suggestions are made for studies regarding important individual species whose life histories are briefly outlined. (Author's synopsis).

Keywords: fishery resources, estuaries, Chesapeake Bay

IV-D-9

Harrington, R.W., Jr., and E.S. Harrington. 1961. Food selection among fishes invading a high subtropical salt marsh: from onset of flooding through the progress of a mosquito brood. *Ecology* 42:646-666.

The study identifies larvivorous and non-larvivorous fishes that frequent salt marshes and adjacent zones of the subtropical halosere in Florida and measures types of food consumed by the fishes.

An abrupt tidal-pluvial flooding allowed fishes in a high salt marsh access to the whole marsh. Some 8,526 samples of 16 species of fishes were collected. The stomach contents of 2,786 fish were (by volume): 35.7 percent plant material, 23.8 percent Aedes mosquitoes, 14.6 percent copepods, 12.5 percent fishes, and 7.8 percent shrimp.

Interactive aspects of food selection among the fishes is discussed with regard to the resources and vicissitudes of their environment, competition for food, and breeding and spatial requirements. (B.W.)

Keywords: fishes, food selection, high salt marsh, U.S. South Atlantic and Gulf coasts

IV-D-10

Thomas J., P. Wagner, and H.C. Loesch. 1971. Studies on the fishes of Barataria Bay, Louisiana, an estuarine community. Louisiana State University, Coastal Studies Bulletin No. 6, Special Sea Grant Issue, pp. 56-66.

An extensive ecological study of two small areas in Barataria Bay area began in March 1969. Seventy-five species of fish representing 65 genera and 40 families were collected with a shrimp trawl in Lake Palourde and Airplane Lake in the southern area and John the Fool Bayou in the northern area. After one year of qualitative studies, a quantitative attempt to estimate fish biomass available to the trawl was initiated in March 1970. The trawl was towed over a premarked distance and the biomass of fish per area was calculated. Preliminary work on stomach analysis of dominant fish, including croaker, spot, sea catfish, bay whiff, and fringed flounder, has been started. Fish are being classified into five general categories ranging from freshwater to truly marine. Seasonality and growth of fish will be studied. (A.A.)

Keywords: fishes, estuarine communities, ecology, Louisiana

IV-D-11

Thomas, J., and H. Loesch. 1970. Some notes on fish collected in the Barataria Bay, Louisiana, region. Louisiana State University, Coastal Studies Bulletin No. 5, Special Sea Grant Issue, pp. 83-96.

Twelve stations in Barataria Bay, Louisiana, were sampled with a shrimp trawl thirteen times from March to December 1969. Thirty-seven species of fish were collected and identified. A table is presented showing stations where each species was collected.

Anchoa mitchilli (bay anchovy) was most abundant; this species was taken at all stations through the year. Micropogon undulatus (croaker) juveniles appeared in November and early December and increased in size and abundance until about June, when the numbers decreased, probably because of fishing pressure. Galeichthys felis (sea catfish) was extremely abundant from late spring to early summer, then declined in abundance; this was followed by a rapid decline as water temperatures fell. The other thirty-four species were less numerous and were taken sporadically. (A.A.)

Keywords: fishes, bay anchovy, croaker, sea catfish, estuaries, Louisiana

IV-D-12

Wagner, P.R. 1973. Seasonal biomass, abundance, and distribution of estuarine dependent fishes in the Caminada Bay system of Louisiana. Ph.D., Thesis. Louisiana State University, Baton Rouge. 193 pp.

This study was the first attempt at measuring fish production quantitatively in the coastal waters of Louisiana. Estimates of actual and potential fish production indicated the Caminada estuary produced more fish per unit area than any estuary previously reported. A minimum of 72.8 gm/m²/yr wet weight or 647.9 lb/yr wet weight was produced which was 42 percent of the maximum potential production available from primary production. The estimated efficiency of conversion of net primary production into secondary fish production was 1.4 percent. (J.B.)

Keywords: estuaries, fishes, biomass, Louisiana

IV-D-13

Tarver, J.W. 1976. An inventory and study of the Lake Pontchartrain-Lake Maurepas estuarine complex. Louisiana Wildlife and Fisheries Commission, Technical Bulletin No. 19. 159 pp.

The study was initiated to investigate the composition, general distribution, and abundance of commercially or potentially important

fauna inhabiting the Lake Pontchartrain-Lake Maurepas estuarine complex, so that comparisons with previously completed wetland research in Louisiana and the northern Gulf of Mexico might enable administrators to efficiently manage Louisiana's renewable coastal zone resources.

Vertebrate and macroinvertebrate populations were sampled with a 16-foot trawl and a 100-foot beach seine. Molluscan benthic communities were empirically determined utilizing a Peterson dredge. Zooplankton was estimated based upon collections accomplished utilizing a No. 2 mesh 1.8 x 0.5 meter net. Hydrological and climatological parameters were collected at four stations in addition to those coinciding with trawl, seine, Peterson, and zooplankton locations. Grain size determinations were made of the upper three inches of sediment samples during two separate sampling efforts--one in 1972 and another in 1973. (A.A.)

Keywords: estuaries, fisheries, marine organisms, Lake Pontchartrain-Lake Maurepas, Louisiana

IV-D-14

Lantz, K.E. 1970. An ecological survey of factors affecting fish production in a Louisiana natural lake and river. Louisiana Wildlife and Fisheries Commission, Fisheries Bulletin No. 6. 92 pp.

This report is a result of a project conducted in the Sabine River and Lac Des Allemands from July 1964 through June 1967. The objectives of this study were: (1) to establish quantitatively what types of aquatic areas are rich, average, and poor in the production of fish and fish food organisms, (2) to determine what cycles occur in the kinds and abundance of plankton and bottom fauna, and (3) to correlate these cyclic occurrences of fish food organisms with variance in fish production in the study areas. Four stations in the Sabine River and three stations in Lac Des Allemands were chosen as sampling sites.

It was found that plankton production in the Sabine River began to increase by February of each year, but counts and weights of net and nannoplankton revealed sporadic high to low values from month to month without predictable trends toward summer maximum productivity. The lack of an extended period of high plankton density was associated with peak stream discharges.

The upper stations on the Sabine River exhibited higher seasonal numbers, volumes, and weights of bottom organisms than found at the two lower stations. Maximum production of bottom fauna occurred each spring in the river.

The two major benthic groups in Lac Des Allemands were Tubificidae and Chironomidae, with Chironomidae species being most abundant during

peak occurrences of bottom fauna. A seasonal peak occurrence of larval Chironomidae occurred each summer, followed by an early fall buildup of the same group. Stomach samples of channel catfish in the summer and winter indicated a good utilization of Chironomidae larvae.

Annual standing crop values of fish in Lac Des Allemands revealed a high poundage of channel catfish (three-year mean of 87 pounds per acre). Collections of fish in the Sabine River indicate species of Centrarchidae and Cyprinidae were common in this drainage, with no major changes in fish populations from that reported by earlier investigators. (H.D.)

Keywords: fish productivity, plankton, food chain, Louisiana

IV-D-15

Zilberberg, M.H. 1966. Seasonal occurrence of fishes in a coastal marsh of northwest Florida. Publications of the Institute of Marine Science, University of Texas 11:127-134.

The biota of a northwest Florida coastal marsh was analyzed, and the relation of salinity and temperature to the fish population was studied for one year. The study area consists of 700 acres of estuarine water and marsh which lie between the Gulf of Mexico and higher ground occupied by stands of Sabal-palm and longleaf pine. Three habitats were studied: woodside canals, ponds, and tidal creeks.

No direct correlation between the abundance of the five species of fish studied and salinity was observed. It was concluded that variations in temperature had a greater influence upon the variation in fish population than did salinity fluctuations. (A.A. and B.W.)

Keywords: fishes, coastal marsh, marsh biota, salinity, Florida

IV-D-16

Hall, C.A. 1971. Migration and metabolism in a stream ecosystem. Ph.D. Thesis. University of North Carolina at Chapel Hill. 418 pp. (Diss. Abstr. 32:881-B)

Fish migration and total stream metabolism were studied in New Hope Creek, North Carolina, from April 1968 to June 1970. Upstream and downstream movement of fishes was monitored using weirs with traps. Most of the 27 species had a consistent pattern of larger fish moving upstream and smaller fish moving downstream. Both upstream and downstream movements were greatest in the spring. For example, in the

spring of 1969 a daily average of 7 fish, weighing a total of 1081 grams, were caught moving upstream, and 17 fish, weighing a total of 472 grams, were caught moving downstream. Although more moved downstream than up, the larger average size of the fish moving upstream resulted in a larger transfer of fish mass upstream.

Diurnal oxygen series were run to measure the metabolism of the aquatic community. Area values of metabolism were similar for different parts of the stream, but both production per volume and respiration per volume were much larger near the headwaters than farther downstream. This was apparently due to the diluting effect of the deeper water downstream. Migration may allow populations to take advantage of such differences in productivity by maintaining young fish in areas of high productivity.

An energy diagram was drawn comparing energies of insolation, currents, photosynthesis, respiration, fish populations, and migrations. Parts of this model were simulated on an analog computer. Input energies from insolation and streamflow were similar. About 0.14 percent of the total respiration of the stream was from fish populations, and over one year about 0.01 percent of the total energy used by the ecosystem was used for the process of migration. If it is assumed that upstream migration is necessary to maintain upstream stocks, which may be periodically decimated by droughts, the migration energy has an amplifying value of 14. (A.A.)

Keywords: stream ecosystem, fish migration, energy flow, North Carolina

IV-D-17

Daiber, F.C. 1974. Tidal marshes of Delaware. Pages 99-149 in H.T. Odum, B.J. Copeland, and E.A. McMahan, eds., Coastal ecosystems of the United States, Vol. 2. Conservation Foundation, Washington, D.C.

The Broadkill River Estuary of Delaware is an example of a salt marsh system showing tidal creek interactions. The estuary was studied by class teams of the University of Delaware, and information is provided on hydrography, biogeochemical cycles, fractionation of inorganic phosphorus, hydrogen sulfide production, distribution of nitrite and nitrate, production and release of nutrients, angiosperm plant material, and caloric studies of Spartina and Sesarma reticulatum (Say).

High salinity penetrated approximately the full length of the small creeks and about half the length of the larger creeks in the study area. The important role of marshes as nurseries in providing food for fishes

was established by sampling waters for planktonic fish eggs and larvae (ichthyoplankton). (B.W.)

Keywords: tidal marshes, coastal ecosystems, estuaries, Delaware

IV-D-18

McErlean, A.J., C. Kerby, and M.L. Wass, eds. 1972. Biota of the Chesapeake Bay. Chesapeake Science 13(Suppl.) 197 pp.

This is a report on the existing conditions of the biota of Chesapeake Bay. The funding agency, the Baltimore District of the U. S. Army Corps of Engineers, requested that the Smithsonian Institution, the University of Maryland, and the Virginia Institute of Marine Science prepare a report on the "Current Status of Knowledge of the Biota of Chesapeake Bay" for inclusion in their "Chesapeake Bay Resource Study."

Objectives of this paper are as follows: (1) To summarize the present state of knowledge about many of the groups of organisms living in the Bay; (2) to provide expert summaries of the current status of research and knowledge on four serious and timely topics--sediments, eutrophication, heavy metals, and pesticides; (3) to review and report on the value of various criteria for measuring the biological effects of environmental changes, with special reference to Chesapeake Bay; and (4) to suggest systems for handling the massive data which must be utilized in managing a complex ecosystem.

Various sections of the issue deal with areas such as: biological criteria of environmental change in Chesapeake Bay; and a discussion of the status of knowledge concerning sampling variation, physiological tolerances, and possible changing criteria for Bay organisms.

Taxa and special effects summaries are provided for a wide range of flora and fauna, including sections on crustaceans, fishes, amphibians, reptiles, and waterfowl.

Systems for analysis of biological data and sample inventories of Bay organisms are also provided. (H.D.)

Keywords: estuarine ecosystems, environmental change, Chesapeake Bay

IV-D-19

Warne, J.E. 1969. Mugu Lagoon, coastal California: origin, sediments, and productivity. Pages 137-154 in A.A. Castanares, ed., Coastal lagoons, a symposium. Universidad Nacional Autónoma de México, Ciudad Universidad.

The geomorphic development, sediments, flora, and fauna of Mugu Lagoon (a shallow coastal lagoon in southern California) are investigated. The lagoon can be divided into several morphologically distinct subenvironments, including the barrier beach, the inlet-tidal delta system, tidal channels, ponds, tidal flats, tidal creeks, marsh, and salt pans.

Plant species of the salt marsh fringing the lagoon are zoned primarily by tidal levels and secondarily by sediment type and drainage characteristics. Twelve marsh halophyte genera are common: Atriplex, Batis, Distichlis, Frankenia, Timonium, Monanthochloe, Salicornia, Suaeda, Jaumea, Triglochin, and Arthrocnemum. Spartina is also present, but much less abundant than in certain other marshes along the California coast. The lowest growth is at about the level of mean-lower high water. Most Pacific coast marshes become established at about this level regardless of the local tide range, suggesting that total submergence is critical to marsh establishment. The low marsh is designated as that zone where only Spartina foliosa, Salicornia bigelovii, and Salicornia pacifica are abundant. This vertical interval of about 0.4m is inundated by the tides at least once daily. At about 1.4m (MLHW), nine halophyte species become well established, and they range upward to 1.8m or more. The upper marsh occupies the vertical range from 1.8 to at least 2.1m.

Rich vegetation, abundant benthonic invertebrates, and large populations of vertebrates living in Mugu Lagoon suggest increased organic productivity relative to coastal waters immediately offshore. It is unlikely that this productivity is dependent upon phytoplankton production. Plankton hauls made in the lagoon were similar in species composition and abundance to those made offshore, and these organisms were probably transported into the lagoon by exchange of tidal waters. The high organic productivity of shallow coastal lagoons is probably due to a characteristic set of conditions prevailing in these regions. Organic matter is produced by diatoms and other algae, eelgrass, and marsh plants. The same mechanisms that concentrate mud in protected locations also operate to concentrate organic matter as these plants die. The mud tends physically and chemically to bind organic matter and serves as a substrate for abundant bacteria. Microbial decay provides basic nutrients for continued primary productivity, organic debris for detritus eaters, and an abundance of bacteria, which is perhaps an important food source. These processes all take place within the photic zone. There is no lag as in deep water, where nutrients released on the bottom must be brought into the photic zone before they can be fixed by photosynthesis and utilized by higher trophic levels. In shallow, restricted areas, relatively greater productivity may result because organic matter is concentrated and the carbon cycle is accelerated. (J.B.)

Keywords: productivity, estuaries, salt marshes, California

IV-D-20

Kilby, J.D. 1955. The fishes of two Gulf coastal marsh areas of Florida. *Tulane Studies in Zoology* 2:175-247.

A study was made of the fish fauna of two coastal marshes on the Gulf coast of Florida to determine, primarily, the composition of those fauna and to discover, if possible, the more obvious ecological factors which were shaping them.

The two areas chosen for study were different ecologically. The one at Bayport had less saline waters and more stable temperatures than the one at Cedar Key. The areas were also quite different with regard to physical and faunal features.

Seventy-five species were recorded during the study and species data are presented in an annotated list. This treatment is supplemented by tables, graphs, and other compilations designed to present certain of the data that could be summarized.

The cyprinodontids were the dominant family of fishes in the brackish waters studied. Despite the relative importance of the factors of salinity and the availability of species, it was noted that the fishes which occur in greatest abundance in the brackish marshes at both Cedar Key and Bayport belong to freshwater groups.

The author concluded that the intertidal marshes at both areas were populated principally by fishes with freshwater, rather than marine, affinities. (Author's summary and B.W.)

Keywords: fishes, coastal marshes, salinity, aquatic ecosystems, Florida

IV-D-21

Hackney, C.T., W.D. Burbanck, and O.P. Hackney. 1976. Biological and physical dynamics of a Georgia tidal creek. *Chesapeake Science* 17:271-280.

Little is known about the interrelationship between marshes and tidal creek communities. Tidal creeks are integrally associated with the salt marshes, since most of the material moving in or out of these areas must pass through tidal creeks. Sixty-five percent of the nation's commercial fish, shellfish and marine sportfish spend all or part of their lives in estuaries. Secondary productivity of estuaries manifested in the productive fisheries is dependent on the productivity of tidal marshes. Tidal creeks may transport the food that nourishes these animals.

This study deals with the species composition, population dynamics, and seasonal distribution of the nekton and epifauna inhabiting a tidal creek in Georgia. Five stations in and near the tidal creek

were compared with respect to their biological and physical components. The study found that small salinity oscillations promoted a high overall diversity of fishes at the headwaters of the creek, even though few fish species maintained permanent populations there. Juvenile fishes were abundant in the summer and fall. Extreme temperature and low dissolved oxygen levels prompted a migration of fishes from these areas in late summer. Permanent fish populations were found at the mouth of the creek and in an adjacent tidal river. (J.B.)

Keywords: tidal marshes, fishes, estuarine animals, productivity, Georgia

IV-D-22

De la Cruz, A.A., and H. Kawanabe. 1967. The population and food habits of fish in a small estuarine pond. *Natural and Applied Science Bulletin* 20:473-477.

The population of two species of fish in a small tidal estuarine pond was estimated by means of the marking and recapture method. Results were compared with figures obtained when actual count of the total fish population was made. Gambusia affinis and Mollienesia latipinna were the two dominant species in the pond numbering 469 (449 by total count) and 120 (105 by total count) respectively. Food habits of the fish were determined by analysis of stomach contents. The fish inhabitants of the pond and one abundant species of shrimp were found to feed on a variety of food items which include both living biota (e.g., micro-algae, small benthic animals, and terrestrial insects) and dead organic material (e.g., organic particular detritus). (A.A.)

Keywords: fishes, food habits, tidal ponds, Sapelo Island, Georgia

IV-D-23

Carr, W.E.S. 1971. Quantitative studies of the feeding habits of juvenile fishes utilizing nursery areas in the estuarine zone. Page 35 in D.S. Gorsline, ed., Second national coastal and shallow water research conference; abstract vol. University of Southern California, Los Angeles. (Abstr.)

Estuarine areas play a vital role in the life cycles of the majority of species of finfish and shellfish that are harvested annually in coastal fisheries. The role of habitats within the estuarine zone as nursery areas is now well documented. The simultaneous occupancy of estuarine nursery areas by the juveniles of many species of fish poses some important problems with regard to the partitioning of

available food resources. Although much is known about the feeding habits and food selection exhibited by the adults and sub-adults of estuarine dependent species, only a limited literature exists on the feeding habits of the smaller juvenile individuals (i.e., individuals less than 50-60 mm in length). Moreover, in those instances in which feeding habits of juvenile fishes have been investigated, the study has usually been confined to but a single species or to a small number of related species.

This investigation was concerned with the feeding habits of the juveniles of all available species of fish inhabiting nursery areas in the near-shore estuarine zone between the Crystal and Withlacoochee Rivers on the northwest coast of Florida. Feeding habits of juvenile fishes were determined by quantitative analyses of gut contents of freshly preserved specimens collected in bi-monthly samples. Analyses provided information on selective feeding, resource and habitat partitioning, interspecific competition, and trophic level and food-chain relationships which are exhibited by these important consumer organisms. (A.A.)

Keywords: food habits, fishes, nursery areas, estuaries, food chain, Florida

IV-D-24

Skinner, J.E. (compiler). 1972. Ecological studies of the Sacramento-San Joaquin estuary. California Department of Fish and Game, Delta Fish and Wildlife Protection Study Report No. 8. 94 pp.

This publication is a result of a study begun in 1961 and is intended to summarize existing knowledge about the principal fish and wildlife resources of the Sacramento-San Joaquin estuary, their ecological relationships, and their environmental requirements, with emphasis on requirements relating to water development. Information is included on phytoplankton, invertebrate animals, fisheries, and waterfowl and other wildlife. Individual articles are discussed elsewhere in this publication. (See III-F-27, IV-D-25, IV-E-28, IV-E-32, and V-A-11.) (B.W.)

Keywords: estuaries, fisheries resources, phytoplankton, invertebrates, waterfowl, wildlife, California

IV-D-25

Stevens, D.E., L.W. Miller, and J.L. Turner. 1972. Other fishes in the estuary. Pages 52-59 in J.E. Skinner (compiler), Ecological studies of the Sacramento-San Joaquin estuary. California Department of Fish and Game, Delta Fish and Wildlife Protection Study Report No. 8.

This section discusses American shad, white sturgeon and the principal resident freshwater fishes of the Delta, which include white catfish, brown bullheads, black crappies, bluegill, largemouth bass, and threadfin shad. These are all important to commercial or sport fishermen. The estuary is important to both the anadromous and resident species as a spawning ground.

Young shad feed on zooplankton and adult shad feed primarily on Neomysis. Benthic organisms are important in the diet of sturgeon. Corophium, Neomysis, and tendipedids were the most frequent food items for all sizes of catfish. Neomysis and Corophium were also the most common food items found in all sizes of black crappie. Phytoplankton and zooplankton were the major food items of threadfin shad. (B.W.)

Keywords: estuaries, fishes, food ecology, California

E. Species Studies

IV-E-1

St. Amant, L.A. 1973. Shellfish and crustacean productivity in marshes and estuaries. Pages 151-161 in R.H. Chabreck, ed., Proceedings of the coastal marsh and estuary management symposium. Louisiana State University, Baton Rouge.

An evaluation of shellfish and crustacean productivity is particularly important when considering coastal marshes and estuaries, since these species are especially estuarine-dependent and represent a level of the productive cycle of estuaries where the harvest of edible protein occurs and economic returns can be measured. Of further significance is the fact that the areas under consideration, the coastal regions from Chesapeake Bay to the Rio Grande River, include approximately 60 percent of the total estuarine habitat of the coastal states, including Alaska, and produce 78 percent of the total annual United States production of estuarine-dependent shellfish and crustacea, valued at more than \$229 million. The paper presented is an attempt to examine this estuarine area and its shellfish and crustacean production in some detail for the period 1965 to 1970.

It is obvious from the extensive production of shellfish and crustacea within the estuarine zones of the South Atlantic and Gulf that such areas are of inestimable value. Since shellfish and crustacea represent only part of the total productivity, and when such areas are evaluated from a recreational and esthetic standpoint, it is obvious that estuarine areas may be the most important ecological systems that must be dealt with. The management of such ecosystems is foreseen to become of major importance in the very near future. From the statistics presented, it is apparent that there is not enough information to determine the exact sites and levels of productivity for various important species within the estuaries. Some of this dearth of knowledge is being overcome by recent investigations and estuarine inventories. Nevertheless, some system should be developed to evaluate or describe specific ecological zones within the estuaries so that a quantitative determination of productivity can be accomplished. There is not much question that environmental impact statements which on the one hand attempt to evaluate the need and economic value of disruptive activities, must also include quantitative and analytical measurements of the natural resource productivity if the public is to offset such proposals and develop acceptable environmental management plans. (A.A.)

Keywords: shellfish, crustaceans, productivity, coastal marshes, estuaries, U.S. South Atlantic and Gulf Coasts

IV-E-2

Idyll, C.P., D.C. Tabb, and B. Yokel. 1968. The value of estuaries to shrimp. Pages 83-90 in J.D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

Information on the importance of estuaries is being gathered more quickly and more precisely than before and it is being made available to the public. The role of the estuaries is still not clear, however. Relatively few estuarine animals appear to be dependent on the estuary for nearly their whole life process.

Some shrimp of the family Penaeidae, especially the genus Penaeus, are good examples of the use of estuaries as nursery grounds. A considerable amount of information is available concerning the numbers, sizes, and other characteristics of shrimp at the edge of the estuary, either entering or leaving. Much less is known about the shrimp during their residence in the estuary itself.

The advantages to shrimp of residence in an estuary during the young stages appear to be of two kinds. In the first place the estuary provides a rich feeding ground. The other advantage is protection from predators and competitors.

Shrimp feed on animals low in the food chain, such as polychaete worms and larval mollusks, and a large part of their food consists of diatoms and other plants at the first trophic level. Hence, they are important converters of energy.

The value of the estuaries to the pink and other commercial shrimp is great and is both direct and indirect. (B.W.)

Keywords: estuaries, shrimp, nursery areas

IV-E-3

Moffett, A.W. 1967. The shrimp fishery in Texas. Texas Parks and Wildlife Department Bulletin 50. 36 pp.

This bulletin indicates that the life histories of all Texas commercial shrimps are similar. In general, the young, hatched in the Gulf of Mexico, are carried by on-shore water movements to the shallow estuaries and coastal lagoons, where they feed, grow rapidly and ultimately return to the Gulf spawning grounds.

The shallow estuaries provide the nursery grounds for the post-larval stages. During this phase of the growth cycle, the shrimp abandon their planktonic way of life and become bottom dwellers. Post-larval and large shrimp are omnivorous bottom-feeders that consume principally algae, small mollusks, marine worms and small crustaceans. (L.H.)

Keywords: shrimp, life cycles, estuaries, food habits, Texas

IV-E-4

Barrett, B.B., and E.J. Ralph. 1976. Environmental conditions relative to shrimp production in coastal Louisiana. Louisiana Wildlife and Fisheries Commission Technical Bulletin 21. 20 pp.

The publication discusses environmental factors that encourage a good brown shrimp harvest: mild water temperatures, low rainfall and river discharge, and high salinities (10 ppt and above) resulting from low freshwater input into estuaries. Low rainfall and river discharges throughout the summer result in above average white shrimp production also. Data are presented for combined good catch years and poor catch years, and for 1975 and 1976. (B.W.)

Keywords: shrimp production, brown shrimp, Louisiana

Barrett, B., and M.C. Gillespie. 1973. Primary factors which influence shrimp production in coastal Louisiana. Louisiana Wildlife and Fisheries Commission Technical Bulletin 9. 28 pp.

Louisiana leads the nation in shrimp production, with an average heads-off yield between 1967 and 1972 of 57 million pounds annually.

Evidence indicates that a critical factor in brown shrimp population survival may be the number of hours water temperatures are below 20°C.

Salinity appears to be a critical factor in distribution and population success. Brown shrimp require salinities over 10 ppt for a successful season. Evidence indicates that a salinity of 19 ppt may be close to the optimum salinity requirements for brown shrimp.

Coastal salinities are directly influenced by rainfall and river water intrusion. After the month of April the combined cause-effect relationships of rainfall and river discharge become dominant in population success and subsequent production. A correlation is noted between river discharge and shrimp production. The spring river discharges were considerably lower during good brown shrimp production years than they were during poor production years. The best white shrimp production years occurred during the lowest summer river discharges, while the poorest years occurred during the highest summer river discharges.

The May brown shrimp catch in the Barataria-Caminada bay area can be used as an index for predicting the subsequent annual total brown shrimp production in Louisiana.

The number of inshore surface water acres utilized as shrimp fishing grounds in coastal Louisiana varies from 2 to 2.85 million acres depending on salinity regimes. Between 1967 and 1972 the annual average inshore total production was 9.2 pounds of shrimp per acre based on the maximum fishing grounds of 2.85 million acres. (A.A.)

Keywords: shrimp production, brown shrimp, salinity, Louisiana

IV-E-6

Gaidry, W.J., and C.J. White. 1973. Investigations of commercially important penaeid shrimp in Louisiana estuaries. Louisiana Wildlife and Fisheries Commission Technical Bulletin 12. 154 pp.

Graphic and tabular data are presented on penaeid shrimp recruitment, growth, and movement. These parameters are related to hydrological conditions existing in the estuarine systems of coastal Louisiana.

The relation between various hydrological conditions and their effects on penaeid shrimp production are also presented. Comparisons are made between the seven coastal areas in relation to life history functions of the two species of penaeid shrimp investigated.

Shrimp populations were sampled at all stages of development, from postlarvae to adult, using specialized gear appropriate for a given development state. Types of gear used were a 0.5-meter plankton net, marsh sled, 6-foot otter trawl, 16-foot otter trawl, and wing nets. From July 1969 to June 1972, over 4,000 biological samples, including 6-foot and 16-foot otter trawls (taken on a regular basis) were made at 60 locations from the Sabine River on the west to the Pearl River on the east. (A.A.)

Keywords: shrimp, estuarine systems, life history, Louisiana

IV-E-7

Loesch, H., and J. Jacob. 1970. Shrimp sampling and preliminary results in two small areas in Barataria Bay, Louisiana. Louisiana State University, Coastal Studies Bulletin No. 5, Special Sea Grant Issue, pp. 65-81.

A low and a high shrimp production area in Barataria Bay, Louisiana, were chosen for a study of the total ecology of these areas. Some difficulties with sampling gear were encountered during the first year of sampling. A shrimp trawl was used, and other gear are still being tested. In May, the southern (high-producing) area had the greatest population of brown shrimp (at least 1,000 per acre); in June, the northern (low-producing) area had the greatest population of brown shrimp. Growth was estimated to be 65 mm in 2 1/2 months. Monthly survival rates were also calculated. White shrimp first appeared in the area in early July but were less abundant than brown shrimp had been. (A.A.)

Keywords: shrimp, productivity, ecology, Louisiana

IV-E-8

Jacob, J., and H. Loesch. 1971. A preliminary two-year comparison of Penaeus aztecus: growth rate, distribution, and biomass in the Barataria Bay area, Louisiana. Louisiana State University, Coastal Studies Bulletin No. 6, Special Sea Grant Issue, pp. 45-55.

Growth rates of brown shrimp in the areas studied were somewhat greater in 1969 than in 1970. This may be due mainly to the far greater number of immigrating shrimp in 1970 than in 1969. John the Fool Bayou, however, had approximately the same peak number of shrimp in both 1969

and 1970. The number of Penaeus aztecus in Airplane Lake and Lake Palourde was declining at the opening of the 1969 commercial shrimping season, whereas it was still rising at the opening of the 1970 season. Growth rates increase as temperatures rise above 20°C and salinities fall below 22 ppt. Growth estimates vary from a minimum of 20 mm per month to a maximum of 45 mm per month. (A.A.)

Keywords: brown shrimp, biomass, estuarine ecosystem, Louisiana

IV-E-9

Wilson, S.B. 1969. Ecological survey of penaeid shrimp of the central Louisiana Gulf coast and estuarine waters. Nicholls State University, Thibodaux, Louisiana. 140 pp.

Brown shrimp, Penaeus aztecus, and white shrimp, Penaeus setiferus, were studied to determine the environments in which they reside during the post-larval, juvenile, and sub-adult stages of their lives.

The dynamics and life cycle of the brown shrimp and white shrimp are reasonably well established. Investigators are relatively certain that these shrimp require two completely different environments for the successful completion of their life cycles. The adults spawn and larvae hatch in the open Gulf waters; the post-larvae then seek a brackish water estuarine habitat, completing development to sub-adult before returning to the more saline waters. It is not completely understood why these organisms migrate from a fairly stable environment, the sea, into one as unstable as the estuaries. Two factors may influence this movement: (1) The protection from predators provided by vegetation and shallow waters and (2) the abundance of organic material. (H.D.)

Keywords: estuaries, brown shrimp, white shrimp, Louisiana

IV-E-10

Barrett, B., and M.C. Gillespie. 1975. 1975 environmental conditions relative to shrimp production in coastal Louisiana. Louisiana Wildlife and Fisheries Commission Technical Bulletin 15. 22 pp.

Shrimp catch data are presented along with environmental factors which influence Louisiana's shrimp harvest. Environmental data for the first four months in 1975 in the Barataria-Caminada Bay area are compared with previous years. The relationship of the number of hours during which water temperatures were below 20°C and shrimp densities are discussed. The influence of salinity patterns, particularly with respect to available nursery areas, is also presented. (A.A.)

Keywords: shrimp production, nursery areas, estuaries, Louisiana

Welsh, B.L. 1975. The role of grass shrimp, Palaemonetes pugio, in a tidal marsh ecosystem. Ecology 56:513-530.

The grass shrimp, Palaemonetes pugio, is a dominant species uniquely adapted to a highly stressed tidal marsh embayment. Monthly sampling of length and dry weight revealed that its life cycle was a single year, with spawning in May, June, and July and most rapid growth in late summer and fall. Mark and recapture estimates conducted quarterly and quadrat net estimates calculated monthly indicated that shrimp were present throughout the year and that densities peaked in the fall (over 1.2 million in 0.01 km² in October). Production of biomass (growth) equaled loss to predation (including decomposition) over the annual cycle, averaging 0.2 kcal/m²/day. Respiration averaged 1.1 kcal/m²/day.

Average daily production per square meter of "total consumables" (fecal pellets = 0.8 kcal, dissolved organic matter [DOM] = 0.7 kcal, biomass = 0.2 kcal) was 60 percent of total ingestion (2.9 kcal); production of feces and DOM thus outweighed biomass production 15:2.

Microcosm studies and observations by scanning electron microscope revealed that shrimp macerated detritus into a heterogeneous assortment of uneaten particles by plucking away the cellular matrix from surfaces of large detrital fragments. This action provided cavities that became heavily invaded by pennate diatoms, and particles that became suspended in the water column and populated by bacteria.

Nutrient analyses indicated the shrimp excreted large quantities of ammonia and phosphate which together with DOM release were presumably responsible for heavy growth of microflora and increased protein fraction in both feces and large and small uneaten detrital fragments.

Palaemonetes pugio, while supporting its own trophic requirements, accelerated breakdown of detritus, preventing blockages of accumulations that might have occurred from pulses of emergent grass and macroalgal detritus in the embayment. This repackaging into feces, heterogeneous fragments, DOM, and shrimp biomass made detrital energy available at a variety of trophic levels, smoothing out organic pulses over time and space, and raising the efficiency of transfer to the food web. The special adaptation of P. pugio to the low-oxygen environment of the decomposer system appeared to limit predation and competition, allowing the shrimp to develop large populations necessary to carry out its role effectively. (A.A.)

Keywords: grass shrimp, tidal marsh, ecosystem, biomass, detritus, U.S. general

IV-E-12

Kutkuhn, J.H. 1966. The role of estuaries in the development and perpetuation of commercial shrimp resources. Pages 16-36 in American Fisheries Society, a symposium on estuarine fisheries. Washington, D.C.

This report summarizes knowledge concerning functional relationships between the estuarine environment and commercial shrimp resources. Discussion is largely restricted to North American species; attention is focused upon situations evolving specifically as a result of the rapid urban and industrial development of the estuary-rich Gulf coast.

The association of shrimp and the brackish-water environment from ontogenetic and ecological points of view is reviewed. Environmental factors and biological factors such as water circulation, temperature, salinity, vegetation, and substratum are discussed. The question of continued productivity and perpetuation of shrimp stocks in the face of man's modifications of estuaries is considered. Measures that could be taken to counteract the effects of coastal wetland development are discussed. (A.A. and B.W.)

Keywords: estuaries, fisheries, shrimp, environmental changes, coastal zones, U.S. Gulf coast

IV-E-13

Welsh, B.L. 1971. The grass shrimp, Palaemonetes pugio, as a systems component of tidal marshes. Page 255 in D.S. Gorsline, ed., Second national coastal and shallow water research conference; abstract vol. University of Southern California, Los Angeles. (Abstr.)

Palaemonetes pugio, the grass shrimp, is an important component of the marsh ecosystem. It processes organic material into highly nutritious fecal pellets and it excretes large amounts of dissolved organics which should stimulate microbial decomposition of the abundant detritus. P. pugio accumulates organic material through rapid growth in the fall with food readily available, then overwinters in the marsh, at low metabolic cost to the system, thus maintaining a storage of readily available animal food to sustain the reproductive growth of immigrating fishes in early spring. The marsh, through rapid and extreme fluctuations of temperature, salinity and oxygen concentration, provides P. pugio protection from competitors and periodic relief from predation.

Present work focuses on quantifying these important interactions. Mark-recapture estimates reached 1.5 million shrimp in three acres in October, dropping to 13,500 in July, with 1:1 sex ratio. Present research indicates females spawn more than once per summer and spring larvae do not grow fast enough to spawn in the fall. Only multiple spawning satisfies the dynamics of population changes without mass immigration of juveniles.

Metabolic studies with laboratory microcosms were used to quantify effects of excreted dissolved organics on microbial metabolism. Fecal matter contributed to the system under field trophic conditions on a 24-hour basis was measured.

The extent to which the marsh offers protection to P. pugio was determined by survival studies in the field with mixed, caged populations of P. pugio, P. vulgaris and Crangon septemspinosus. P. pugio has exhibited physiological adaptation to low O_2 in the water. The habitat regularly becomes nearly anaerobic at night, and this probably is the most significant stress in regard to eliminating the two potential competitors from the area. (A.A.)

Keywords: grass shrimp, tidal marshes, marsh ecosystems, fecal pellets, U.S. coastal regions

IV-E-14

Mock, C. R. 1966. Natural and altered estuarine habitats of Penaeid shrimp. Proceedings of the Gulf and Caribbean Fisheries Institute 19:86-98.

This study demonstrates what can happen to a shrimp nursery area when it is altered by bulkheading. Two areas were chosen--one adjacent to an unaltered vegetative shore and the other near a concrete bulkhead. Both had similar hydrology and sediment types, but differed in the amount of organic detritus in the bottom sediments and in water depth. Intensive sampling over a 10-month period indicated that 2.5 times more brown shrimp (Penaeus aztecus) and fourteen times more white shrimp (P. setiferus) were produced from the natural habitat than from the bulkhead area. This preference for the unaltered habitat depended on the physical rather than the hydrologic characteristics of the habitat. (A.A.)

Keywords: shrimp, estuarine habitats, detritus, environmental change, Florida

IV-E-15

Rekas, A.M.B. 1973. The migration of post larval Penaeus aztecus and P. setiferus into a Louisiana nursery area (Airplane Lake). M.S. Thesis. Louisiana State University, Baton Rouge, Louisiana. 79 pp.

A study of the migration of post-larval brown shrimp (Penaeus aztecus Ives) into Airplane Lake, Louisiana, was started in March 1972. Sampling gear included tide traps, a marsh sled, and a one-meter plankton net. Stations were located in the most direct route to Airplane Lake. Tide trap collection periods were six hours long for a 24-hour period at 10 primary collection stations. A marsh sled was

pulled 10 feet at seven selected locations in or near Airplane Lake. A one-meter plankton net was fished for 15 minutes in the middle of a major pass into Bay St. Honore.

Laboratory techniques were developed to separate by genus and count the specimens of animals that looked like shrimp. Post-larval brown shrimp (P. aztecus) and white shrimp (P. setiferus) were removed from the samples, identified, counted, and measured.

The results indicated that 99 percent of the post-larvae migrate on flood tides. Most of the larvae were caught at the surface day or night, but more post-larvae were caught during the night than during the day. During periods of a new or full moon, more post-larvae were caught at all depths than during periods of first quarter or last quarter moon.

Most post-larvae were found to migrate toward Airplane Lake by the most direct route using the main channel currents rather than following the bay edges or crossing open bays without major currents.

Some post-larvae dropped out of the main channel currents and used the primary bays and bayous as nursery areas. The abundance of post-larvae in Airplane Lake was found to be 0.135 post-larvae per square meter.

In deep channel water, more post-larvae were caught near the bottom than at the surface on bright sunny days.

Tables are provided showing the catch at each station over all trips. (A.A.)

Keywords: shrimp, behavior patterns, nursery areas, Louisiana

IV-E-16

Wallace, D.H. 1966. Oysters in the estuarine environment. Pages 68-73 in American Fisheries Society, A symposium on estuarine fisheries. Washington, D.C.

Production of oysters in many parts of the United States has been reduced by environmental changes in the estuaries. Most of these changes have been man-made and include such things as chemical and biological contamination of the waters, physical destruction of the bottom through dredging for fill material and channels, and alteration of current and salinity patterns. Overfishing has decreased populations in some estuaries, and diseases and predators have limited the ability of oyster farmers to maintain a high level of production.

Inability to produce seed commercially on a sustained basis has been another limiting factor in oyster culture in the Middle Atlantic area. Commercial hatcheries and utilization of salt ponds for seed control hold promise for the future. Research is needed on diseases and their control, techniques for control of predators, and improved methods for seed production. Eventually, a substantial part of the production of oysters, particularly for the raw-bar trade, will come from scientifically controlled artificial systems, eliminating many of the factors which limit production under natural conditions. While these techniques are being perfected, suspended culture and use of salt ponds where conditions can be controlled to some extent offer possibilities for continued production of quality oysters. (A.A., expanded)

Keywords: oysters, estuarine communities, environmental change, U.S. coastal regions

IV-E-17

Reintjes, J.W. 1969. The Gulf menhaden and our changing estuaries. Proceedings of the Gulf and Caribbean Fisheries Institute 22:87-105.

This publication contains a brief review of the role of estuaries in the life cycle of Gulf menhaden, Brevoortia patronus. Estuaries are a vital link in the life of Gulf menhaden. Surveys of 36 selected Gulf coast estuaries give indexes of the relative abundance of juvenile menhaden. These juveniles enter the purse seine fishery the next year and also the year following as 2-year-olds. Record landings of nearly 1.2 billion pounds were made in 1969. Approximately 90 percent of the catch are menhaden in their second and third year of life. (A.A.)

Keywords: menhaden, estuaries, U.S. Gulf coast

IV-E-18

June, F.C., and J.L. Chamberlin. 1958. The role of the estuary in the life history and biology of Atlantic menhaden. Proceedings of the Gulf and Caribbean Fisheries Institute 11:41-45.

Between Cape Canaveral and Cape Cod, there are approximately thirty-eight estuarine systems that provide an environmental link in the life history and biology of the Atlantic menhaden (Brevoortia tyrannus). Larvae enter the estuaries and congregate near the upstream limits of the tidal zone where they metamorphose into juveniles. After spending the summer months in the estuary, the schools of juveniles move out into the ocean. The one-year-olds make up the bulk of the purse seine fishery along the south Atlantic Coast and in Chesapeake Bay, but large numbers occur in the sounds and rivers. Part of the adult population also utilizes the estuaries for feeding purposes during the late winter and early spring.

It appears that the availability and variety of food is the single most important factor concerning the distribution of larvae and juveniles. The low salinity of the upper estuary is a critical factor in the development and growth of the young. Water temperature also is related to certain life history features and behavior patterns of the fish, especially the winter occurrence of larvae at the river mouths and the fall emigration of juveniles from the estuaries. (B.W.)

Keywords: estuaries, life history, menhaden, U.S. Atlantic coast

IV-E-19

Suttkus, R.D. 1956. Early life history of the Gulf menhaden, Brevoortia patronus, in Louisiana. Pages 390-407 in J.B. Trefethen, ed., Transactions of the seventy-first North American wildlife conference, Wildlife Management Institute, Washington, D.C.

Results of the study indicate that menhaden (Brevoortia patronus) utilize estuarine waters as a breeding zone. (H.D.)

Keywords: Gulf menhaden, life history, Louisiana

IV-E-20

Jeffries, H.P. 1975. Diets of juvenile Atlantic menhaden in three estuarine habitats as determined from fatty acid composition of gut contents. Journal of the Fisheries Research Board of Canada 32:587-592.

Juvenile Atlantic menhaden (Brevoortia tyrannus) feed on zooplankton and particulate organic matter, but the importance of each material in the diet cannot be visually determined, because food is ground to an amorphous paste in the fish's gizzard-like stomach. During early digestion in the anterior alimentary canal, fatty acids do not appear to change significantly, at least with respect to relative concentrations of saturated and unsaturated groups. Because zooplankton and particulate organic matter have markedly different fatty acid compositions, a hypothetical mixture of the two components can be calculated that best accounts for the observed fatty acid distributions of gut contents. Decreasing reliance on zooplankton, from bay through river to marsh, probably reflects resource abundances in three habitats and demonstrates adaptability of juvenile menhaden to different food supplies. (A.A.)

Keywords: Atlantic menhaden, estuarine habitats, zooplankton

IV-E-21

Adkins, G. 1972. A study of the blue crab fishery in Louisiana. Louisiana Wildlife and Fisheries Commission Technical Bulletin 3. 57 pp.

On July 1, 1969, a project entitled "A study of the blue crab fishery in Louisiana" was initiated in Study Area IV, Timbalier-Terrebonne Bays and vicinity, Terrebonne and Lafourche Parishes, Louisiana. This project was terminated June 30, 1972. Field activities consisted of weekly, monthly, and quarterly sampling at various stations with 16- and 6-foot otter trawls and 0.5-meter plankton net.

The blue crab commercial fishery has, for the past decade, contributed to Louisiana's seafood industry an average of 9,032,520 pounds of hard crabs annually, with an average dockside value of \$621,025.

Adult blue crabs were taken in sampling gear during all months of the year and in all recorded salinities and temperatures. Larval crabs were taken in all months, with larger catches occurring during late winter and spring. Juvenile crabs (less than 50 mm carapace width) occurred in greatest numbers during winter and early spring, with the largest catches occurring in low salinity waters. Male crabs dominated fresher waters; females tended to move back and forth within the sampling area dependent upon hydrological conditions and spawning periods. (A.A. modified)

Keywords: blue crab, fisheries, Louisiana

IV-E-22

Jaworski, E. 1972. The blue crab fishery, Barataria Estuary, Louisiana. Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana. Publication No. LSU-SG-72-01. 112 pp.

Although it is one of the state's major commercial fisheries, the blue crab fishery of Louisiana has been given low research priority. This study was designed to generate field data on the crab fishing patterns and ecology of the crab population of a single estuarine system.

By analyzing the crab-fishing patterns of the Barataria estuary, Louisiana, a model of the ontogenetic distribution of the crab population was generated. An estuary and the adjacent marine area constitute a complete crab habitat. As the blue crab passes through various stages of its life cycle, specific environments of the estuarine system are occupied as subhabitats. The spawning, wintering, and maturation subhabitats were identified by associating crabs in a particular life stage, as reflected in the crab fishermen's landings, with a specific portion of the estuary. The resulting subhabitat model predicts the

location of several segments of the crab population and partially explains the five crab migration patterns that were observed in the estuary.

Pages 5-24 are particularly relevant to productivity of estuarine areas. One chapter describes the physical environment in terms of blue crab habitat and associated hydrologic conditions. Barataria Bay is found to be a shallow and dynamic blue crab habitat characterized by marked fluctuations in salinity, water temperature, circulation, and other hydrologic variables. The blue crab population must be able to adjust to such a dynamic ecosystem. The following section on the life history of the blue crab describes relationships between salinity, food supply, and life stage and patterns of distribution and migration. The section on crab fishing patterns contains field data on the relationships between the crab and its subhabitats.

A second chapter traces the life history of the blue crab with a description and discussions of its life cycle in an estuary, salinity and osmoregulation, and food items and trophic level. The blue crab is described as a motile, euryhaline organism which occupies particular subhabitats according to the physiological requirements of each life stage, including salinity, water temperature, and food supply. (A.A. and G.S.)

Keywords: blue crab, fisheries, estuarine habitat, life histories, Louisiana

IV-E-23

Darnell, R.M. 1959. Studies of the life history of the blue crab (Callinectes sapidus Rathbun) in Louisiana waters. Transactions of the American Fisheries Society 88:294-304.

Analysis of 133 plankton, 462 otter trawl, and 124 shore seine samples from Lake Pontchartrain and adjacent waters of southeastern Louisiana suggests the following pattern for the life history of the blue crab in the area. Mating takes place in the fresher areas, followed by migration of the mated females to more saline waters. After hatching, the young migrate in toward the estuaries where most of the growth takes place. The first wave of young seems to arrive in Lake Pontchartrain in May, and crabs spawned in the spring appear to reach a size of about 65 mm by September of the first year. The relative absence of adults from winter collections suggests migration or hibernation. Food habits, parasites, and periodicity are discussed. (A.A. modified)

Keywords: blue crab, life history, Louisiana

IV-E-24

Ropes, J.W. 1968. The feeding habits of the green crab, Carcinus maenas. Fishery Bulletin 67(2):183-197.

Green crabs are believed to be the cause of a decline during the 1940s in the commercial landings of the soft-shell clam. Collections of 3,979 green crabs from Plum Island Sound, and vicinity in 1954-56 provided the samples for a study of their feeding habits. Crabs were caught at the edges of salt marshes by opening caves in the banks of Spartina. Estimates of the amount of food in the stomachs were divided into three categories based on tissue or hard parts of food.

Some foods were eaten frequently by certain groups of crabs. Spartina was found most often in intertidal crabs. Plant foods, especially Spartina, were abundant near the caves inhabited by green crabs and on islands that were relatively near the subtidal zone. In general, all sizes of crabs ingested the same kinds of foods; differences in foods were minor. Pelecypods were most frequent in crabs 30 to 59 mm wide. (L.H.)

Keywords: green crab, Spartina, plant foods, upper U.S. Atlantic coast

IV-E-25

Dunham, F. 1972. A study of commercially important estuarine-dependent industrial fishes. Louisiana Wildlife and Fisheries Commission Technical Bulletin 4. 63 pp.

A study of commercially important estuarine-dependent industrial fishes was conducted from July 1969 through June 1972 in the area of the Barataria and Caminada Bays in the parishes of Lafourche, Jefferson, and Plaquemines in Louisiana. The purpose of the project was to aid the fishing industry in the best utilization of fish resources. Data were obtained both from field samples, which included those taken with a 0.5-meter plankton net and a 16-foot otter trawl, and samples taken at industrial fish companies.

The most abundant species (54.7 percent) in the trawl samples was bay anchovy (Anchoa mitchilli) and the most abundant commercial fish species was Atlantic croaker (Micropogon undulatus). The monitoring of fish eggs and larvae entering the bay revealed seasonal influxes, but did not always give a true representation of the abundance of juvenile, sub-adult, and adult fish populations.

Samples from industrial bottom-fish catches showed that Atlantic croaker make up over 65 percent of the total catch. Only a small

percentage (.05-1.5 percent) of the catch from menhaden vessels were species other than menhaden. (A.A.)

Keywords: estuarine ecosystems, commercial fishes, bay anchovy, croaker, menhaden, Louisiana

IV-E-26

Arnoldi, D.C., W.H. Herke, and E.J. Clairain. 1973. Estimate of growth rate and length of stay in a marsh nursery of juvenile Atlantic croaker, Micropogon undulatus (Linnaeus), "sandblasted" with fluorescent pigments. Proceedings of the Gulf and Caribbean Fisheries Institute 26:158-172.

Atlantic croaker constitute over half the industrial bottomfish landings from the Gulf of Mexico. Most length frequency studies indicate the mean standard length at one year of age does not exceed 130 mm, but two recent papers dispute this.

Project objectives were to determine juvenile croaker growth rates in the marsh and how long the fish remain there. About 90,000 croaker, from 10 to 40 mm standard length, were "sandblasted" with fluorescent pigment, and released as they entered a marsh nursery. Recapture attempts were by trawling in the nursery and trapping at the outlet.

Sixty definitely marked croaker were recaptured. These meager returns suggest individual croaker remain in the marsh only one to four months and grow about 14 mm per month. Croaker in industrial bottomfish landings generally range from 80 to 160 mm; thus, most may be less than 12 months old. Also, turnover rate of croaker using the marsh may be high enough to make the industry dependent on maintenance of a viable marsh nursery. (A.A.)

Keywords: marsh nursery, croakers, productivity, U.S. Gulf coast

IV-E-27

Rickards, W.L. 1968. Ecology and growth of juvenile tarpon, Megalops atlanticus, in a Georgia salt marsh. Bulletin of Marine Science 18:220-239.

Juvenile tarpon were found in both still and flowing dark water in marsh pools and creeks on Sapelo Island, Georgia. These fish grew approximately three centimeters per month. Two populations of juveniles were found during 1964: a resident population and a second one driven shoreward from the Gulf stream by Hurricane Dora. Tarpon from the second population grew approximately half as fast as those of the first population. Fish in the second influx encountered lower

temperatures and less abundant food earlier in their existence than did those of the first population. The latter were probably the only ones to survive to migrate to warmer waters late in November.

Post-larval tarpon are strictly carnivorous and they are predominantly piscivorous. The principal food varies with relative availability of different food organisms. The size of the food consumed is directly related to the size of the tarpon. Juveniles less than 125 mm in standard length consumed large numbers of ostracods; shrimps (Palaemonetes spp.) were eaten by tarpon longer than 75 mm in standard length. Fishes, mainly Gambusia affinis, were eaten by tarpon of all sizes sampled. Birds appear to be the principal predators of juvenile tarpon. (A.A.)

Keywords: tarpon, salt marsh, Georgia

IV-E-28

Jensen, P. 1972. King salmon. Pages 44-51 in J.E. Skinner (compiler), Ecological studies of the Sacramento-San Joaquin estuary. California Department of Fish and Game, Delta Fish and Wildlife Protection Study Report No. 8.

King salmon support a commercial, as well as a sport, fishery in California. The estuary influences salmon populations primarily because it is the migration route between the ocean and inland spawning areas. Little is known regarding growth of Sacramento River king salmon from the time they leave the estuary as 3-inch outmigrants until they begin to appear in ocean fishery landings as 20-inch fish in the late summer of their second year. (B.W.)

Keywords: estuaries, commercial fishes, sport fishes, California

IV-E-29

Gerke, R.J., and V.W. Kaczynski. 1972. Food of juvenile pink and chum salmon in Puget Sound, Washington. Washington Department of Fisheries Technical Report 10. 27 pp.

Pink and chum salmon (Onchorhynchus gorbuscho and O. keta) were collected from three widely separated onshore areas of Puget Sound during April, May, and early June 1970 to determine the kinds and types of organisms in the diet. Sampling areas included: Anderson Island (southern Puget Sound), Port Susan (central Puget Sound), and Toandos Peninsula (Hood Canal). Fish collected from the Anderson Island area fed almost exclusively on harpacticoid copepods (95 percent of the stomach contents). Food items consumed at the other sampling

site indicated a more varied diet, which included gammarid amphipods, barnacle nauplii, euphausiids, harpacticoid copepods, and eggs of invertebrate animals.

Epibenthic forms, and not zooplankton, were found to be the most important food types. (Whether the epibenthic forms are the preferred food type is not known since tests were not made on food selectivity.) Accordingly, the ecological zone that the epibenthic organisms inhabit is of primary concern when alteration of the shoreline areas and beaches is being considered. Piers, jetties, landfills, marinas, bulkheads, and other facilities that disturb or destroy beach area could be highly detrimental to aquatic life, especially the kind that lives in association with the bottom substrata. Not only do these salt-water installations remove living area for commercially important fishes, but they also eliminate habitat that supports the food these fishes feed upon. (A.A., expanded)

Keywords: salmon, food habits, environmental changes, Washington, Puget Sound

IV-E-30

Chadwick, H.K. 1971. Striped bass and water development in the Sacramento-San Joaquin estuary. Pages 58-68 in P.A. Douglas and R.H. Stroud, eds., A symposium on the biological significance of estuaries. Sport Fishing Institute, Washington, D.C.

Anadromous fisheries resources in California are affected directly by ecological changes in rivers and estuaries as a result of water development. Striped bass are strictly sport fish in California, and they support the most valuable fishery in the Sacramento-San Joaquin estuary.

This paper illustrates how water development affects fisheries resources in the estuary by describing the effect of water development on ecological requirements of striped bass. Programs to alleviate potential adverse effects are also discussed. The discussion is limited to effects associated with water storage and distribution. The effects of pollution, dredging, and filling, although important, are not included in the discussion.

Loss of eggs and larvae, reduction in zooplankton and benthos populations in delta channels, loss of migrating adults, reduction of spawning area and lower survival rates of young bass, are anticipated effects of water development. (B.W.)

Keywords: fisheries, sport fisheries, zooplankton, estuarine management, California

IV-E-31

Talbot, G.B. 1966. Estuarine environmental requirements and limiting factors for striped bass. Pages 37-49 in American Fisheries Society, a symposium on estuarine fisheries. Washington, D.C.

Although striped bass can thrive in certain river systems that are not estuarine in character, their requirements are such that they are usually found in estuarine areas during part or all of their life cycle. As with other anadromous fishes, adequate spawning areas appear to be the most critical necessity for survival of striped bass. The requirements for spawning are discussed, including such factors as stream length, fishways, water velocity, water quality, turbidity, and water temperature. Degradation of estuaries by dredging, filling, dam building, poor agricultural practices, and pollution are a continuing menace to striped bass populations. The following recommendations for research are presented: (1) studies to determine the origin of the small striped bass, (2) toxicity of various pollutants, (3) cooperative research by biologists and engineers on water supply projects, (4) improved methods of artificial propagation, and (5) detailed studies of estuaries to determine their contribution to productivity. (A.A. and B.W.)

Keywords: estuaries, fishes, environmental changes, productivity, U.S. general

IV-E-32

Turner, J.L. 1972. Striped bass. Pages 36-43 in J.E. Skinner (compiler), Ecological studies of the Sacramento-San Joaquin estuary. California Department of Fish and Game, Delta Fish and Wildlife Protection Study Report No. 8.

Striped bass are one of California's top-ranking sport fish. Studies show that the fish are dependent on the estuary for spawning and development of larvae and young.

Their energy for the first few days is derived from the larval yolk sacs. By the seventh or eighth day the larvae begin to feed actively on small zooplankton. The copepod, Eurytemora affinis, is the major food item in the western Delta until the larvae reach 0.6 inch in length, at which time the mysid shrimp, Neomysis awatchensi, become the major food. After their first year, juvenile striped bass progressively increase the amount of fish in their diet, although Neomysis remains important. (B.W.)

Keywords: sport fisheries, estuaries, food habits, California

IV-E-33

Simmons, M.A., R.M. Sitts, J.T. Allen, and A.W. Knight. 1974. The nomenclature for Mysids in the Sacramento-San Joaquin delta estuary. California Fish and Game 60(1):23-25.

Several mysids (Neomysis spp.) are found in brackish and fresh waters from Monterey Bay north along the western coast of North America. One particular mysid, the opossum shrimp, is important as a food item in the diet of young-of-the-year striped bass (Morone saxatilis) in the Sacramento-San Joaquin Delta Estuary System. The description and discussion which follow a brief introduction present historic and taxonomic evidence for transferring the mysid form found in this estuary system from Neomysis arvatochensis (Brandt) to Neomysis intermedia (Czerniavsky). (L.H.)

Keywords: mysids, opossum shrimp, estuarine systems, California

IV-E-34

Tabb, D.C. 1966. The estuary as a habitat for spotted seatrout, Cynoscion nebulosus. Pages 59-67 in American Fisheries Society, A symposium on estuarine fisheries. Washington, D.C.

The spotted seatrout, Cynoscion nebulosus (Cuvier), is one of the most valuable fish of the southeastern United States. In several states spotted seatrout are harvested in about equal quantities by sport and commercial fishermen. Both young and adults are tolerant of the normal environmental extremes of estuaries, which are too rigorous for most marine fishes. This enables the spotted seatrout to reproduce and grow almost unhindered by predation and competition.

Spotted seatrout populations of more northern estuaries apparently make seaward movements to escape winter cold. Southern populations do not exhibit a strong offshore movement. They are nearly nonmigratory in Florida, and tagging studies show that they seldom move more than 30 miles. Since most of the favored estuarine areas are separated by long stretches of exposed seashore, there is little exchange of stocks between estuary systems. The nonmigratory character of the species, when combined with differences in habitat, has resulted in spotted seatrout populations having different growth rates.

Unfavorable conditions for feeding or spawning in any given estuary, which cause declines in abundance, are likely to be felt for long periods since the region will not likely receive large numbers of immigrants from other estuaries. Destruction of the estuarine habitat will have an immediate and direct effect on the abundance of the spotted seatrout, and reversal of such effects will be slow.

Although the biology of spotted seatrout is fairly well known, there are some obvious deficiencies in the information. There is a scarcity of detailed knowledge of the ecology of spawning and regional differences in habits due to differences in the environment. (A.A., expanded)

Keywords: estuarine communities, commercial fishes, fisheries,
U.S. south Atlantic and Gulf coasts

IV-E-35

Saila, S. B. 1961. The contribution of estuaries to the offshore winter flounder fishery in Rhode Island. Proceedings of the Gulf and Caribbean Fisheries Institute 14:95-109.

The winter flounder, Pseudopleuronectes americanus (Walbaum), has been found to be one of the important demersal fishes of Rhode Island. The contribution of particular breeding areas and the significance of shallow estuarine environments to the offshore flounder fishery were studied by means of mark-recapture population estimation procedures. The adult breeding population in one salt pond (Green Hill Pond, Charlestown, Rhode Island) was inventoried. In addition, an estimate of the offshore population, as well as the population of juvenile winter flounder in another salt pond, was obtained. On the basis of the juvenile population estimate, it was found that about 25 percent of the total recruits to the offshore fishery were contributed by two shallow lagoons. An estimate of the mortality rate from egg to juvenile (age 1) was also made, indicating a survival of about 18 individuals from each 100,000 newly hatched eggs. It was concluded from the projected population estimates that a significant contribution to the fishery was derived from the shallow estuarine environments. (A.A.)

Keywords: estuaries, winter flounder, fisheries, Rhode Island

IV-E-36

Vince, S., I. Valiela, N. Backus, and J.M. Teal. 1976. Predation by the salt marsh killifish Fundulus heteroclitus (L.) in relation to prey size and habitat structure: consequences for prey distribution and abundance. Journal of Experimental Marine Biology and Ecology 23:255-266.

Laboratory feeding preference experiments show that the maximum size of prey eaten [the snail Melampus bidentatus (Say)] and the amphipod Orchestia grillus (Bosc) increases with increasing size of the predator, Fundulus heteroclitus (L.). Melampus greater than 7 mm in shell height escape predation by even the largest killifish. In the laboratory, consumption of prey is reduced in high marsh habitat relative to low marsh, particularly in the case of larger fish. Low marsh has few

grass stems per unit area, while high marsh is considerably more complex, with dense small stems providing cover for prey and reducing successful fish hunting. The population of Melampus in low marsh within Great Sippewissett salt marsh consists mainly of large snails but this size is rare in high marsh. The size distribution is inverse for Orchestia, with large amphipods more abundant in high marsh. The construction of fences excluding Fundulus from the marsh surface led to low marsh size distributions of Melampus and Orchestia resembling those of high marsh, in agreement with the laboratory results. Killifish predation seems to be an important factor regulating the abundance and size distribution of the two prey species in the two marsh habitats. (A.A.)

Keywords: salt marshes, killifishes, food preference

IV-E-37

Darnell, R.M., and T.E. Wissing. 1965. Nitrogen turnover and food relationships of the pinfish Lagodon rhomboides in a North Carolina estuary. Pages 81-110 in F.J. Vernberg, ed., Physiological ecology of estuarine organisms. University of South Carolina Press, Columbia.

Estuarine systems are widely recognized as areas of high fertility and as feeding and nursery areas for a variety of coastal fishes and invertebrates. It has been suggested that most of the nutrients passing to the consumer species do so through the medium of detrital food chains. Yet, with a few notable exceptions, knowledge of the quantitative dynamics of nutrient turnover by individual detritus feeding species is limited. To some extent, the heart of this estuarine problem has been ignored. This study attempts to correct that condition through a discussion of nitrogen turnover in pinfish feeding on detrital matter and other nutrients trapped on the blades of eelgrass. (J.B.)

Keywords: nitrogen turnover, food relationships, pinfish, estuaries, North Carolina

F. Seagrass Fauna Studies

IV-F-1

Wood, E.J., W.E. Odum, and J.C. Zieman. 1969. Influence of sea grasses on the productivity of coastal lagoons. Pages 495-502 in A.A. Castanares, ed., Coastal lagoons, symposium. Universidad Nacional Autónoma de México, Ciudad Universidad.

Sea grasses in coastal lagoons act in several ways to control or modify the ecosystem: 1) They act as food for a very limited number of organisms such as the parrotfishes, surgeon fishes, Australian garfishes, the Queen

conch, sea urchins, and some nudibranchs. The green sea turtle formerly grazed heavily on the turtle grass, hence the name. It has been found, however, that certain urchins grind up the seagrasses but do not appear to digest them, and this may well apply to other animals which appear to graze on them. 2) seagrasses serve as hosts for large numbers of epiphytes which are grazed extensively, for example, by the mullets. These epiphytes may be comparable in biomass with the seagrasses themselves. 3) seagrasses provide large quantities of detrital material which serves as food for certain animal species and for microbes which in turn are used as food by larger animals. 4) seagrasses provide organic matter to initiate sulfate reduction and an active sulfur cycle. 5) seagrasses bind the sediments and prevent erosion. This also preserves the microbial flora of the sediment and the sediment-water interface. 6) seagrasses tend to collect organic and inorganic material by slowing down currents and stabilizing the sediments. 7) the seagrasses have a rapid rate of growth (up to 9 mm per day, average 2 to 4 mm per day) and produce between 2.2 and 10 gm of dry leaf per m² per day.

The study also contains a brief comparison of Thalassia and Spartina with respect to production of detritus. (A.A.-modified)

Keywords: seagrasses, productivity, coastal ecosystems

IV-F-2

Phillips, R.C. 1960. Observations on the ecology and distribution of the Florida seagrasses. Florida State Board of Conservation Marine Laboratory, St. Petersburg, Professional Papers Series No. 2. 72 pp.

In 1957, a program of seagrass research was initiated by the Florida State Board of conservation. The initial work, which is described in this report, consisted of studies in distribution, ecology, and growth rates.

Florida has over 3,000 miles of coastline whose extremes extend from the tropical to the warm temperate zones. Natural physical forces have created barrier islands and offshore keys with abundant shallow quiet water conditions in many areas of the state which became favorable habitats for the establishment and growth of submerged plants. Plants constitute the basic link in the food chain and are the producing group of organisms in the food pyramid. Among these plants, there are four important seagrasses in Florida waters; namely, Thalassia testudinum Konig, Syringodium filiforme Kutz (= Cymodocea manatorum Aschers), Diplanthera wrightii Aschers (= Halodule wrightii Aschers), and Ruppia maritima L. Two species of Halophila occur in Florida (H. baillonis Aschers and H. engelmannii Aschers), but are not treated extensively in this paper owing to infrequency of occurrence and sparse abundance when found.

Fishing in Florida is a million dollar industry. Seagrass beds are nursery and feeding grounds for young fish and shrimp. Countless populations of small marine animals, upon which the shrimp and fish feed, are attracted to the nutrient-rich grass beds. Organic addition from leaf death and decay adds to the substrate in certain situations. This attracts foraging animals, such as fishes, worms and small crustacea as well as bacteria. The nutrients released into the water when seagrass leaves decay help to support a large plankton population, which in turn supports an abundance of larger animals, and so on up the food chain.

The seagrasses, directly or indirectly, may be called food producers. Their presence is essential to the presence and growth of many species of marine life, especially in the younger stages of their development. They also provide a support for numerous epiphytic organisms of similar importance. If the food producer is eliminated, the absence affects organisms progressively up the pyramid until the pinnacle, man in this instance, is reached. The effect upon man if this were to happen would not be realized immediately but would gradually be felt.

Dredging and filling for creation of real estate has been increasing to an alarming rate in Florida. In most cases the areas most suitable for these activities are the shallow areas which support the seagrass growths. With the present emphasis upon utilizing the products of the sea, more careful attention will have to be focused upon the food pyramid, and, in this instance, upon the role the seagrasses play in the overall picture. It will be necessary to limit certain activities such as dredging and filling which are inimical to marine plants.
(Author's introduction)

Keywords: seagrasses, ecology, food pyramid, fisheries, environmental changes, Florida

IV-F-3

Adams, S.M. 1976. The ecology of eelgrass, Zostera marina (L.), fish communities; structural analysis. Journal of Experimental Marine Biology and Ecology 22:269-291.

Fish populations utilizing eelgrass, Zostera marina (L.), beds in two different estuarine areas near Beaufort, North Carolina, were analyzed and compared to determine aspects of their community structure. The fish community of the eelgrass beds was characterized by low diversity and high standing crops of biomass and energy, both of which showed seasonal variation. Wide temperature fluctuations related to the overall shallowness of the beds probably regulated the diversity of fishes utilizing the beds. This community was dominated by

pinfish, Lagodon rhomboides (L.), which comprised 45 percent and 67 percent of the fish biomass in the Phillips Island and Bogue Sound beds, respectively.

Changes in total body caloric content were probably related to developmental stages and changes in diet. Adult fish often had significantly higher weight-specific caloric contents than juvenile fish. Monthly or seasonal variations in caloric content of the organic matter of pinfish had little influence on the caloric content within the various sizes of pinfish.

There was a significant correlation between fish biomass, temperature, and Zostera biomass. Fish biomass was higher when temperature and grass biomass were at a maximum. In general, water depth over the beds had little effect on the standing crop of fish within the bed, but cooler waters which occurred at night, darkness, or both, had a large effect. (A.A.)

Keywords: eelgrass, fish communities, estuaries, biomass, North Carolina

IV-F-4

Adams, S.M. 1976. The ecology of eelgrass, Zostera marina (L.), fish communities, functional analysis. Journal of Experimental Marine Biology and Ecology 22:293-311.

Consumption, production, and respiration of fish communities utilizing two eelgrass beds in a shallow estuarine system near Beaufort, North Carolina, have been estimated for 1971-1972: annual production was 21.7 kcal/m^2 in each bed with pinfish accounting for 45 and 68 percent of the production in the Phillips Island and Bogue Sound beds, respectively. Annual community respiration was 57.9 and 69.7 kcal/m^2 in the two beds with pinfish accounting for 62.6 and 26.7 percent of the total in the Bogue Sound and Phillips Island beds, respectively. Estimation of the annual food energy consumed by the eelgrass fish community using the Winberg and daily ration methods gave values within 6 percent of each other.

Energy turnover was high (2.8), and the efficiency of energy dissipation low for the two eelgrass fish communities, suggesting that the resident fish populations were adapted to the temperature extremes within the bed. High ecological efficiencies of 0.24 and 0.23 and the high overall efficiency of the eelgrass system (production/solar radiation) of 0.0051 and 0.0086 percent indicate that the eelgrass beds are efficient systems for converting consumed energy and solar radiation into fish. (A.A.)

Keywords: eelgrass, fish communities, productivity, estuarine system, pinfish, North Carolina

IV-F-5

Thayer, G.W., and S.M. Adams. 1975. Structural and functional aspects of a recently established Zostera marina community. Pages 518-540 in L.E. Cronin, ed., Estuarine research, Vol. 1. Academic Press, New York.

Although the value of eel-grass productivity to an ecosystem has been recognized for over 50 years, little quantitative information is available on any major portion of the eel-grass community in North America, save for on the grass itself. The epifaunal and infaunal invertebrates and the fishes inhabiting a grass bed in the Newport River estuary are dominated by only a few species. The density and biomass of these groups are considerably greater than in the adjacent unvegetated portions of the estuary. Fishes using the grass bed appeared to exert some control over the density of the epifaunal community.

The macrofauna in the bed consume an amount of energy equivalent to 55 percent of the net production of eel-grass, phytoplankton, and benthic algae in the bed. There is sufficient available energy to support the estimated bacteria-microfauna-meiofauna compartment. The data further suggest that there is an excess of plant production in the bed, a portion of which is increasing the organic content of the sediments. The remainder is probably exported to the adjoining estuary. This export may be highly significant to the trophic function of the shallow estuarine system near Beaufort, since eel-grass is estimated to supply as much as 64 percent of the total production of phytoplankton, cord grass and eel-grass in this system. (A.A.)

Keywords: eelgrass, productivity, biomass, invertebrates, estuarine system

V. MARSH AS HABITAT AND FEEDING GROUNDS

A. Marsh Populations

V-A-1

Shanholtzer, G.F. 1974. Relationship of vertebrates to salt marsh plants. Pages 463-474 in R. J. Reimold and W. H. Queen, eds., Ecology of halophytes. Academic Press, New York.

Significant salt marsh plant-vertebrate relationships exist in areas subject to tidal-saline waters. Their associations assume both direct and indirect dimensions. Results of direct plant-vertebrate associations tend to be more immediate in their expression than do indirect relationships. It is the intent of this paper to describe and evaluate these relationships.

Direct relationships involve spatial and physical utilization of salt marsh plants by vertebrates. Spatial utilization patterns are derived from the territory, home range, and behavior of vertebrate species using the halophyte dominated marsh environment and the structure of the plants themselves.

Marsh vegetation provides a habitat and a structural foundation for the feeding, reproductive, and roosting activities of many vertebrates. In addition, plant cover provides a moderate thermal environment and refuge from predation. Thermal considerations are important during periods of avian incubation when excessive solar radiation can damage eggs and young.

Halophytes are used by vertebrates for nutritive and non-nutritive purposes. Consumption for nutritive purposes involves mainly granivorous and whole plant grazing. With the production of seeds, some birds and possibly the rice rat develop a granivorous mode of feeding. Seaside sparrows, sharp-tailed sparrows, and red-winged blackbirds are some species that utilize this source of protein and energy.

Relatively little marsh grass is grazed while in the living state, and most of that is probably harvested by insects. Deer, marsh rabbits, and rodents are a few vertebrate herbivores that enter the marsh for feeding. Most of these species restrict their activities to high marsh zones. (J.B.)

Keywords: vertebrates, salt marsh plants, halophytes, plant-vertebrate relationships

V-A-2

Kraeuter, J.N., and P.L. Wolf. 1974. The relationship of marine macro-invertebrates to salt marsh plants. Pages 449-462 in R.J. Reimold and W.H. Queen, eds., *Ecology of halophytes*. Academic Press, New York.

In spite of the numerous ecological works on salt marsh plants, most of which are concerned with zonation, primary production, or nutrient requirements, the effects of the invertebrates on the vegetation have received little attention. Some workers have listed large numbers of marine invertebrate species inhabiting the marsh, but when the creeks, pools, and similar areas are eliminated, only a few species remain to dominate the marsh proper.

The marsh continuum includes the areas covered by halophytes, barren areas called pannes, pools surrounded by grasses, and the creeks that drain the surface. For purposes of the study the salt marsh is considered to begin where halophytes other than submerged aquatics appear. Pools and drainage creeks are not included in the scope of the study.

Summarizing the effects of invertebrates on halophytes, the authors divide both the marine invertebrates and the insects into two major groups: 1) those that live directly on plant tissues; and 2) those living on detritus and algae. The majority of the marine invertebrates are algal-detrital feeders and have no direct effect on the halophytes. In general, they enter the terrestrial food chain by raccoons, clapper rails, ibis, and waterfowl; and they enter the marine food chain as larval forms or as food for crabs such as Eurytium and Callinectes or fish breeding in the marsh. The insects eating plant tissue and sap obviously do direct harm to the halophytes, though consumption probably does not exceed 10 percent.

A useful bibliography is included. (J.B.)

Keywords: marine macroinvertebrates, salt marsh plants, halophytes, food chain, plant-invertebrate relationships

V-A-3

Ursin, M.J. 1972. Life in and around the salt marshes. Thomas Y. Crowell Co., New York. 110 pp.

The book presents descriptions of plants and animals and habitats that are commonly observed in salt marshes. It also includes many species of plants and animals that are frequently encountered in the marshes but are not regular inhabitants.

Each section is divided into two parts: (1) a brief general discussion of the interrelationships of the plant or animal species; and (2) chart presentations of common and important species.

Kinds of marshes, marine plankton, plant life, lower marine invertebrates, higher marine invertebrates, and national wildlife refuges are discussed. (H.D.)

Keywords: salt marshes, habitat, ecology

V-A-4

Palmisano, A.W. 1973. Habitat preference of waterfowl and fur animals in the northern Gulf coast marshes. Pages 163-190 in R.H. Chabreck, ed., Proceedings of the coastal marsh and estuary management symposium. Louisiana State University, Baton Rouge.

The marsh-estuarine environment is regarded as one of the most productive natural environments on earth. The interface between terrestrial, oceanic, and fluvial habitats offers conditions of high nutrient and water availability, protective nursery grounds for the abundant development of marine organisms, and convenient harvest areas. An ideal combination of these factors is responsible for this phenomenal productivity. This paper deals primarily with waterfowl and fur-bearing animals in the coastal marshes of Louisiana. Since different habitat types are not equally preferred by all animals, the coastal marshes were subdivided, first, on the basis of geologic origin into southwestern Louisiana (The Chenier Plain) and southeastern Louisiana (The Deltaic Plain).

The value of the coastal zone to fur-bearing animals and waterfowl is related in large part to the diversity of plant communities. Conditions of optimum nutrient and water availability and a long growing season insure maximum primary productivity. Vigorous plant communities which support optimum populations of fur-bearing animals and waterfowl are an excellent index to the overall "health" or well-being of the entire estuarine ecosystem. This is especially true of muskrat and nutria populations whose life histories are intimately tied to the marsh vegetation. Peak production of these animals is often the result of maximum primary production of sedges and grasses and vigorous overall primary productivity. These ideal conditions presently exist only in areas of maximum habitat diversity. Continued productivity requires that this diversity be maintained and that processes, both natural and manmade, which tend to reduce natural habitat diversity, be altered so as to maintain or enhance optimum conditions. (A.A.)

Keywords: waterfowl, fur animals, habitat preference, coastal marshes, primary productivity, U.S. Gulf coast

V-A-5

Chabreck, R.H. 1971. Ponds and lakes of the Louisiana coastal marshes and their value to fish and wildlife. Proceedings of the twenty-fifth annual conference of the Southeastern Association of Game and Fish Commissioners, pp. 206-215.

The broad, flat coastal region of Louisiana is one of the unique areas of the world. The vast marshes, interlaced with bayous, ponds and lakes, combine to make the area extremely productive for fish and wildlife. Ponds and lakes add tremendous diversity to the region and serve as concentration areas for the energy flow from adjacent marshes.

Tidal ponds and lakes are important nursery and feeding grounds for many marine organisms. Ponds and lakes are extremely important for ducks and coots (Fulica americana), and the wintering populations using such areas number several million. Alligators (Alligator mississippiensis) plus valuable fur-bearing animals, such as mink (Mustela vison) and otter (Lutra canadensis) depend on ponds and lakes for survival. Also, nutria (Myocastor coypus) are closely associated with water areas, and often use ponds and lakes for escape and travel lanes, and aquatic vegetation for food. Wading birds and shore birds along the Louisiana coast depend heavily on ponds and lakes for a source of food.

A survey of the Louisiana coastal area disclosed that ponds and lakes make up one-fourth of the area. The ponds and lakes range from less than 0.01 acre to over 400,000 acres in size and had an aggregate area of 5.3 million acres. The study showed that the fresh, brackish and intermediate marshes are of high value to waterfowl because of high pond density and plant growth. Ponds and lakes in the saline marshes are of low value to most waterfowl, but of extreme importance to marine organisms.

This study was undertaken to determine the basic ecological factors influencing the distribution of important wildlife food plants in coastal Louisiana. Laboratory experiments were conducted to determine the effects of salinity on seed germination and plant growth. All species examined, except Sesuvium portulacastrum, exhibited significant reduction of germination with increasing salinity. Relative response was determined by comparing regression equations for each species. Two different response types were detected, linear and quadratic. Distichlis spicata, Scirpus olneyi, Scirpus americanus and Setaria magna were in the linear response group. They are listed in decreasing order of salinity tolerance. In the quadratic response group were, Echinochloa walteri, Oryza sativa, Scirpus robustus, Polygonum pensylvanicum and Sacciolepis striata. These species are also listed in order of decreasing salinity tolerance. The slope of the regression equation was used to compare the salinity tolerance; and the "Y" intercept, the theoretical germination in distilled water.

Growth experiments were carried out under greenhouse conditions using sand culture techniques. Salinity reduced the growth of all species tested. Scirpus olneyi and Scirpus robustus exhibited high growth rates at low salinity levels but growth was severely restricted at salinities over 20 ppt NaCl. Growth rates of Distichlis spicata and Spartina patens were slower at low salinities but were less affected by higher levels. Regression equations were used to describe the effect of salinity on plant growth. (A.A. and G.S.)

Keywords: coastal marshes, fish, wildlife food plants, tidal ponds and lakes, marsh grasses, Louisiana

V-A-6

McGinnis, J.T., R.A. Ewing, C.A. Willingham, S.E. Rogers, D.H. Douglass, and D.L. Morrison. 1973. Final report on environmental aspects of gas pipeline operations in the Louisiana coastal marshes to the Offshore Pipeline Committee. Battelle Memorial Institute, Columbus, Ohio. 95 pp.

This environmental impact statement contains an excellent brief review of the vegetation and associated fauna of the Louisiana coastal parishes. A bibliography is included. (J.B.)

Keywords: environmental change, coastal marshes, Louisiana

V-A-7

Chabreck, R.H. 1968. The relation of cattle and cattle grazing to marsh wildlife and plants in Louisiana. Proceedings of the twenty-second annual conference of the Southeastern Association of Game and Fish Commissioners, pp. 55-68.

The firm marsh soils along the southwestern Louisiana coast are very fertile and support dense growths of vegetation, and as such serve as ideal cattle range. Also, the long growing season provides year-round grazing and frequently range cattle can maintain their weight even during winter months. However, these marshes are also very productive for various wildlife species such as migratory waterfowl, rails and snipe (Capella gallinago), plus numerous fur-bearing animals.

This area each year winters over 2 million ducks or 30 percent of the ducks in the Mississippi Flyway. In addition some 300,000 blue and snow geese winter in this area plus untold number of snipe, coots (Fulica americana) and rails. The fur harvest has declined in recent years, but is still valued at over \$1 million.

The relationship between cattle grazing and wildlife varies considerably, depending upon the cattle stocking rate, months that grazing is done, plants present and the wildlife species concerned. This relationship can be manipulated to a large degree by the landowner to suit the desired land use practice.

The following summation is a list of the various game species and their relationship to cattle and cattle grazing in the coastal marshes of Louisiana.

BLUE AND SNOW GEESE. These birds benefit from moderate cattle grazing. They feed primarily on tender, new growth of marsh grasses, plus roots and rhizomes that they dig from the soil, and are attracted to clean areas where dense stands of mature vegetation have been removed. Not only is more food available in such areas, but also the birds prefer areas having an unobstructed view and offering protection from approaching danger.

DUCKS. Unlike geese, ducks have feeding habits and habitat requirements differing greatly from cattle. Whereas cattle depend mainly on the foliage of marsh grasses, ducks feed on seeds and aquatic vegetation. Many marshes are too soft to support the weight of cattle, but where cattle can graze they open up dense stands of mature vegetation and permit sub-climax species to grow. Also these openings provide feeding areas for ducks. Annual grasses are excellent cattle forage. Also, the seeds of these grasses are choice duck foods. Therefore, where cattle are permitted to graze annual grasses throughout the summer, seed production is greatly reduced.

Ideal duck habitat should contain from 4 to 6 inches of permanent water throughout the winter. Then, dewatering freshwater marshes during the late spring and summer will afford conditions favorable for the germination and growth of annual grasses. However, the permanent dewatering of fresh, brackish or salt marshes to develop cattle pasture simply removes that much area from duck usage and the marsh condition no longer exists.

SNIPE. Probably no game species benefits more from cattle grazing than does the Wilson snipe. This species feeds on earthworms, insects, snails and occasionally seeds and prefers exposed moist soil with no overhead cover. In fact the largest concentrations of snipe are usually found on overgrazed marsh range.

RAILS. Louisiana has several species of rails but none are affected by moderate cattle grazing. This species likes an "edge effect" and will do well where cattle have opened up dense stands of mature vegetation. The rail must have adequate escape cover, but seldom are marshes so heavily overgrazed that such is not available.

FUR-BEARING ANIMALS. At one time the fur industry in Louisiana was a multi-million dollar industry; but, with the gradual disappearance of the muskrat, its value has steadily declined. However, in areas that still have muskrat and suitable habitat, anything more than light to moderate grazing would be detrimental. (Author's introduction and summary)

Keywords: cattle grazing, marsh fauna, marsh plants, Louisiana

V-A-8

Palmisano, A.W., Jr. 1967. Ecological factors affecting occurrence of Scirpus olneyi and Scirpus robustus in the Louisiana coastal marshes. Proceedings of the twenty-first annual conference of the Southeastern Association of Game and Fish Commissioners, pp. 161-172.

Louisiana contains an estimated 4,000,000 acres of coastal marsh, which provides a livelihood and recreation for thousands of people through fishing, hunting and trapping. This vast area serves as the wintering ground for over 6,000,000 ducks, geese and coots, nearly one-fourth of the total United States waterfowl population. These marshes are also the leading fur-producing habitat in the nation. Over \$4,000,000 worth of furs were taken in Louisiana during the 1964-1965 trapping season. This figure, however, is less than half of the value of muskrats (Ondatra zibethicus) alone in the 1946-1947 trapping season, when over 8,000,000 muskrat skins worth \$8,029,746 were trapped. This decline in muskrat production closely parallels the reduction and deterioration of prime marshlands once dominated by two sedges, three-cornered sedge (Scirpus olneyi) and leafy three-cornered sedge (Scirpus robustus), long recognized as choice foods for muskrats and blue geese (Chen caerulescens) in Louisiana's coastal marshes.

In the brackish marshes of the state, these important plants are now excluded from vast areas by more competitive species such as couch grass (Spartina patens), saltmarsh grass (Distichlis spicata) and in some instances big cordgrass (Spartina cynosuroides), all of which tend to form closed stands. The reason or reasons for the inability of the choice sedges to compete successfully with these grasses are not clear. Therefore, this study was undertaken to investigate the basic ecological factors influencing establishment and growth of Scirpus olneyi and Scirpus robustus communities.

Distribution of S. olneyi was associated with slight depressions in the interior of marshes where minimum water levels ranged from -8.0 to +2.0 inches. The maximum soil salinity recorded in these communities was 16,000 ppm and the minimum recorded was 10,100 ppm. The pH of the soil ranged from 4.1 to 6.0. Soil water had higher maximum salinity and pH values than the soil.

S. robustus tolerated higher salinity and greater water level fluctuation than S. olneyi. In S. robustus communities soil salinities ranged from 12,000 to 22,000 ppm; water depths ranged from -6.0 and +5.0 inches; and soil pH ranged from 5.6 to 6.4. Communities of S. robustus were often associated with disturbed sites, and this species is a primary invader in areas of exposed soil in brackish marshes subjected to slight water level fluctuation.

Optimum seed germination of both sedges was at temperatures that fluctuated on a daily cycle from 20°C to 35°C; light was a very important factor influencing germination. Submergence by only one inch of water inhibited germination. A sharp decline in the percent germination of S. robustus occurred between 8,000 and 10,500 ppm salinity. The germination of S. olneyi was reduced 50 percent at 4,000 ppm salinity. (Author's introduction and summary)

Keywords: coastal marsh, waterfowl, fur-producing habitat, marsh grasses, Scirpus, Louisiana

V-A-9

Rutzler, K. 1969. The mangrove community; aspects of its structure, faunistics and ecology. Pages 515-535 in A.A. Castanares, ed., Coastal lagoons, a symposium. Universidad Nacional Autonoma de Mexico, Ciudad Universidad.

In a brief survey of the literature dealing with mangroves in the sense of a littoral habitat, the points of focus and results of earlier works are summarized. The various biotopes within the community are classified in accordance with their dominant floristic and faunistic components. It is felt that not enough consideration has been given to the sedentary fauna which is reaching dominant importance on mangrove roots in certain regions. The limited abundance and peculiarity of the substrate raise interesting problems concerning interspecific relations and dynamics of associations.

A large number of habitats in mangrove swamps are influenced by the sea. These have been greatly neglected by systematists and ecologists in the past. With coordinated international and interdisciplinary cooperation, it should be possible, with reasonable effort, to determine the community structure; i.e. the correlation and self-determination of the biocenotic units. (A.A.)

Keywords: Mangroves, estuarine animals, ecology

V-A-10

Sewell, G.H. 1971. Economic and social value of estuarine wildlife, Appendix C, pages C-1 through C-10 in The economic and social importance of estuaries. Estuarine Pollution Study Series No. 2. U.S. Environmental Protection Agency, U.S. Government Printing Office, Washington, D. C.

Estuarine wildlife can be classified into four categories excluding fishery resources, with differing economic and social significance for the United States population. They are: (1) fur-bearing mammals, (2) game waterfowl, (3) "exotic" shore birds, and (4) the common wildlife that can tolerate human presence. Each category represents a drastically different relationship to the human community; and within the individual categories wide variations can be found in the degree of dependence upon estuarine conditions.

The sale of pelts from commercially-trapped fur-bearing mammals provides an indication of economic value. In the 1965-66 trapping season, trappers in the coastal marshes of the Gulf and Atlantic states sold approximately \$5 million in fur and possibly \$1 million in meat. Louisiana was the primary producer with a total value of approximately \$4,600,000. Roughly \$4 million of this is attributed to the 3.5 million acres of coastal marsh. The annual value of fur production is highly unstable, and the variation from one year to the next can be as great as 50 percent.

Saline waters burn marsh vegetation, especially the primary food plants for fur-bearers. Therefore, minimization of saltwater intrusion into fresh or brackish waters is necessary. Subsequently, the marshes managed for fur production are not normally available for most typical aquatic estuarine life, especially shrimp and fish that use the estuaries as a nursery.

Hurricanes and man-made intrusions upon fur-producing marshes have represented the most serious threats to fur-bearing animals and their habitat. Navigational construction projects, highway construction, canal systems, dredging and filling, flood-control works, pollution, and other encroachments of physical development and urbanization are slowly removing significant areas of marsh.

On a national scale, the harvesting of pelts from marsh animals is a miniscule industry. The industry is susceptible to domestication, fur farming being the primary source of mink pelts. Because of the managed nature of the fur-production marshes and their weak ecological relationship with the estuaries, the fur production industry does not appear to be a major victim of man-made estuarine change.

Waterfowl--primarily ducks and geese--represent both an aesthetic and a recreation industry resource. Most species do not appear to be particularly dependent on any aspect of the estuarine zone, as they are able to use freshwater marshes, lakes, and ponds with equal ease.

"Exotic" shore and sea birds are discussed, with emphasis on pelicans, cormorants, eagles, ospreys, and waders. Many naturalists believe that few of these species are in danger of extinction, and respectable numbers of most species can be maintained by wise planning in the estuarine zones.

The author concludes that the monetary value of estuarine uses that conflict with wildlife will rise, intensifying the existing conflict. However, since the wildlife appears sufficiently adaptable, some compromise and considerable planning can preserve the major wildlife populations and serve the critical needs of the United States society. (H.D.)

Keywords: wildlife, fur-bearing animals, waterfowl, shore birds, planning and management, U.S. general

V-A-11

Mall, R., and G. Rollins. 1972. Wildlife resource requirements, waterfowl and the Suisun Marsh. Pages 60-68 in J.E. Skinner (compiler), Ecological studies of the Sacramento-San Joaquin estuary. California Department of Fish and Game, Delta Fish and Wildlife Protection Study Report No. 8.

The Suisun Marsh, consisting of approximately 55,000 acres of marsh land and 30,000 acres of bays and sloughs, plays an important role in providing wintering habitat for waterfowl of the Pacific Flyway. Aside from its importance to wintering populations, the marsh provides critical habitat for many other wildlife forms, including the bald eagle, peregrine falcon, California clapper rail, white-tailed kite, black rail, salt-marsh harvest mouse, and Suisun shrew. The existence of this wide variety of wildlife is possible because of: (1) The relatively large expanse of unbroken native habitat and (2) the diversity of vegetation and aquatic conditions that prevail in the marsh.

Studies have shown that seeds from two plant species in particular provide the bulk of the winter food supply. These are alkali bulrush and brass buttons. However, some plant species are more abundant but provide little in the way of food. These include pickleweed, salt-grass, and cattail. (B.W.)

Keywords: wildlife, habitats, waterfowl, saltmarsh plants, California

V-A-12

Miller, A.W., R.S. Miller, H.C. Cohen, and R.F. Schultze. 1975. Suisun marsh study, Solano County, California. U.S. Department of Agriculture Soil Conservation Service, Davis, California. 186 pp.

Suisun Marsh plays an important part in providing habitat for waterfowl of the Pacific flyway. It is important to many other types of wildlife and fish and in addition, this 57,000 acres of marshland along with the 27,000 acres of sloughs and bays is valuable as open space for recreation activities. Planned reductions in delta outflow may seriously increase salinities and degrade water quality for maintenance and management of the marsh habitat.

If this happens, vegetative changes will occur that will substantially reduce the waterfowl carrying capacity of the marsh. Research and experience indicate that soil salinities must be maintained at a level that desirable marsh plants can tolerate or the quality of waterfowl habitat will deteriorate. (B.W.)

Keywords: waterfowl, habitat, coastal marsh, environmental change, California

B. Birds

V-B-1

Bent, A.C. 1963. Life histories of North American marsh birds. Dover Publications, New York. 392 pp.

This is a general work that provides basic information on marsh birds. (G.S.)

Keywords: marsh birds, life histories, U.S. general

V-B-2

Bent, A.C. 1962. Life histories of North American shore birds. Dover Publications, New York. 2 Vols.

Members of the family Anatidae are described in this general work.

Keywords: waterfowl, life histories, U.S. general

V-B-3

Bent, A.C. 1962. Life histories of North American shore birds. Dover Publications, New York. 2 Vols.

This is a general work that provides basic information on seven families of shore birds. (G.S.)

Keywords: shore birds, life histories, U.S. general

V-B-4

Bent, A.C. 1963. Life histories of North American gulls and terns. Dover Publications, New York. 337 pp.

This is a general work that contains basic information on gulls and terns. (G.S.)

Keywords: gulls, terns, life histories, food habits, U.S. general

V-B-5

Bent, A.C. 1964. Life histories of North American petrels and pelicans
Dover Publications, New York. 335 pp.

Basic information on petrels and pelicans of North America is provided in this general work. (G.S.)

Keywords: petrels, pelicans, life histories, food habits, U.S. general

V-B-6

Bent, A.C. 1963. Life histories of North America diving birds. Dover
Publications, New York. 239 pp.

This is a general work containing basic information on diving birds. Species described include grebes, loons, puffins, auklets, murrelets, guillemots, murres, and auks. (G.S.)

Keywords: diving birds, life histories, food habits, U.S. general

V-B-7

Small, A. 1974. The birds of California. Winchester Press, New York.
310 pp.

A checklist of all of the birds of California, grouped by families, is provided. Information concerning the distribution of birds, land regions, and climate in California is provided. Habitat, which ranges from the sea and seacoast to mountain forests and man-created habitat, is discussed. An annotated list of the birds of California is given showing seasonal status, habitat, and range. (H.D.)

Keywords: birds, seacoast habitat, California

V-B-8

Smith, F.W. 1973. A study of waterfowl habitats, populations and fluctuations in the lower Trinity River and the upper Trinity Bay, Texas. Ph.D. Thesis. Texas A&M University. 222 pp. (Diss. Abstr. 33:2950-B)

Waterfowl habitats, populations, and fluctuations were studied from 1968 to 1971 in a 20,000-acre marsh on the Texas Gulf coast. The marsh was type-mapped and 5 major vegetation zones were designated: (1) Intermediate marsh; (2) salt-water marsh; (3) fresh-water marsh; (4) wooded swamp; (5) controlled waterlevel salt marsh.

A total of 55 plant species occurred in the study area. Paspalum lividum was the major species, constituting 27.8 percent of the vegetative composition. Major species of the vegetation zones were Paspalum lividum in zones 1, 2, and 5; Alternanthera philoxeroides in zone 3; and Phyla lanceolata in zone 4. Coefficients of similarity, calculated for comparison of vegetation zones, ranged from 0.0 to 0.366. Soil salinity and pH values indicated an increase in salinity and acidity as sampling approached Trinity Bay. Waterfowl were observed every month, with February and October contributing the largest numbers, and June and July the smallest. No waterfowl nests were found, but 1 wood duck and 6 mottled duck broods were observed. Analysis of mean waterfowl numbers showed some significant and highly significant differences between months, vegetation zones, and waterfowl groups. Food habits for 371 waterfowl collected were determined. Plant materials comprised 100 percent of the total food volume of geese. Native grasses composed 80.9 percent of the total volume and were the most important food item consumed. Other marsh plants represented 18.6 percent, and cultivated rice (Oryza sativa) contributed only 0.5 percent. Fourteen duck species were analyzed to determine dietary patterns. Plant materials comprised 87.5 percent of all foods, while animal matter made up 12.5 percent. Cultivated rice was the most important plant food, representing 31 percent of the total food volume. Indices of similarities computed for duck food habits ranged from 0.154 to 0.749 and were used to differentiate the ducks into 3 divisions. (A.A.)

Keywords: waterfowl, coastal marsh, marsh plants, Texas

V-B-9

Lynch, J.J. 1968. Values of the South Atlantic and Gulf Coast marshes and estuaries to waterfowl. Pages 51-63 in J.D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

The author describes the environmental opportunities afforded to waterfowl by the wetlands of the South Atlantic and Gulf coasts. He distinguished between the utility of environments and the value to waterfowl, describing value as worth, relative to need or some other intangible. Waterfowl discussed include: swans, geese, brant, dabbling ducks, and diving ducks. Lynch states that, by using information now available regarding environmental requirements and tolerances of waterfowl, it is possible to discern some values of coastal wetlands to certain species of waterfowl. The true worth of the tidal marsh lies not so much in direct appeal to waterfowl, but rather in subtle contributions to waterfowl food-chains of adjacent coastal environments. (B.W.)

Keywords: salt marshes, estuaries, waterfowl, U.S. South Atlantic and Gulf coasts

V-B-10

Sprunt, A. 1968. Values of the South Atlantic and Gulf coast marshes and estuaries to birds other than waterfowl. Pages 64-72 in J.D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

The paper is concerned with those groups and species of water birds that are most closely associated with marshes and estuaries: pelicans and cormorants; the long-legged waders; eagles and ospreys; cranes and rails; shorebirds; gulls and terns. Sprunt maintains that no general statements can be made regarding the values of wetland habitats to these groups and presents the requirements of the various birds group by group, and in some cases, species by species.

The marsh and estuarine environments of the South Atlantic and Gulf coasts are more than likely going to be changed by man. However, Sprunt sees no reason to believe that any of the species discussed would be eliminated if ecological considerations are included in long-range planning. (B.W.)

Keywords: coastal marshes, estuaries, birds, U.S. South Atlantic and Gulf coasts

V-B-11

Heppner, F.H., and L.L. Gould. 1973. Birds of the Atlantic seaboard from Cape Hatteras to Cape Cod. Pages 8-1 through 8-138 in S.B. Saila, ed., Coastal and offshore environmental inventory: Cape Hatteras to Nantucket shoals. Marine Publication Series No. 2, University of Rhode Island, Kingston.

To date, 380 species of birds have been reported from coastal lands and offshore waters of the Middle Atlantic Bight. The distribution, migration patterns, population levels, and life histories of these birds are presented and discussed.

Long-term increases in human population levels within the study area have directly and indirectly influenced the composition and numbers of the regional avifauna. Specific factors, which include changing patterns of land use, are discussed with reference to long-term changes in the numbers and kinds of birds in the area.

The coastline between Capes Cod and Hatteras, which is deeply indented with a series of estuaries and bays, profoundly influences the migration patterns of birds. Certain coastal land areas are discussed in terms of their importance as concentrating points for birds in passage. Regions that host high concentrations of breeding birds and wintering birds are identified in terms of the species composition. The economic, agricultural, and esthetic value of the bird populations are evaluated in terms of the relationship between birds and man.

Recent years have seen dramatic changes in the population levels of a number of species. Factors contributing to these changes are discussed, and future trends are forecast relating to possible increases or decreases among individual species and species composition. (S.B. Saila, chapter synopsis)

Keywords: birds, coastal marshes, estuarine areas, Cape Hatteras, Cape Cod

V-B-12

Chamberlain, E.B., Jr. 1960. Florida waterfowl populations, habitats and management. Florida Game and Fresh Water Fish Commission Technical Bulletin No. 7. 62 pp.

This study was designed to gather information on the distribution and abundance of resident and migratory waterfowl in Florida and their utilization of the various habitats, to classify and evaluate these various types of waterfowl habitats, to develop techniques for improving and managing them, and to investigate the effects of various land use practices.

Areas covered in the study include general descriptions, scope of investigations, habitat studies, population studies, harvest, hunting economics, and land use management.

Certain land use practices are detrimental to waterfowl. Draining dredging, and filling in of marshlands result in a severe loss of waterfowl habitat. (H.D.)

Keywords: waterfowl, habitats, environmental changes, Florida

V-B-13

Robert, H.C., J.M. Teal, and E.P. Odum. 1956. Summer birds of Sapelo Island, Georgia: a preliminary list. The Oriole 21:37-45.

The authors present a list of birds observed on Sapelo Island during June, July, and August 1955 and 1956. Some breeding records in May are included, as well as some comparisons with earlier works.

Because of the large areas of shallow-water habitats, the wading birds are the conspicuous species on Sapelo Island. Three species that are associated with the marsh community are the clapper rail, long-billed marsh wren, and seaside sparrow.

The list is divided into three parts: 1) species that breed on the island; 2) species that do not breed on the island even though they

may commonly occur for all or part of the summer; and 3) species of casual occurrence. (B.W.)

Keywords: birds, habitats, coastal marshes, Georgia

V-B-14

Martin, A.C., and F.M. Uhler. 1951. Food of game ducks in the United States and Canada. U.S. Fish and Wildlife Service Research Report No. 30. 157 pp.

A statistical index to the preferred duck foods in the various regions of the United States and Canada is presented on the basis of an analysis of nearly 8,000 stomachs or gullets of 18 species of game ducks. The study also contains illustrations of the principal food items and gives practical suggestions for waterfowl food management. (J.B.)

Keywords: game ducks, food habits, waterfowl, U.S. and Canada

V-B-15

Anderson, W. 1960. A study of waterfowl nesting in the Suisun marshes. California Fish and Game 46:217-226.

The Suisun Marshes, an area comprising approximately 140 square miles in Solano County, California, was the site of a duck nesting study conducted from late April to July 1, 1959. The objectives of this study were to evaluate production as compared with that of 1953, and to determine factors which would limit nesting.

The results of this study confirmed earlier beliefs regarding the limitations of the Suisun Marsh as a waterfowl breeding area. No specific factor could be singled out as a sufficiently important reason why this area should not support a far larger nesting population than it does. (L.H.)

Keywords: waterfowl nesting, coastal marshes, California

V-B-16

Rollins, G.L. 1973. Relationships between soil salinity and the salinity of applied water in the Suisun Marsh of California. California Fish and Game 59:5-35.

It has been predicted that, as a result of upstream water diversions, the salinity of channel water in the Suisun Marsh area in 1990 will be

from two to three times greater in the late spring and early fall than it is at present. The results of this study show that this increase in channel water salinities will result in substantial increases in soil salinities when the water is applied to the duck hunting clubs in the locale. Such widespread increases in soil salinities could be expected to reduce the amount of important waterfowl food plants and ultimately decrease the value of the Suisun Marsh as a waterfowl wintering area. (L.H.)

Keywords: marsh salinity, soil salinity, waterfowl food plants,
California

V-B-17

Wheeler, R.J., and S.W. Harris. 1970. Duck nesting and production in the Humboldt Bay area of California. California Fish and Game 56:180-187.

The nesting season for mallards (Anas platyrhynchos) lasted about 145 days in 1964 and 130 days in 1965. The nesting season for cinnamon teal (Anas cyanoptera) lasted about 135 days in 1964 and 115 days in 1965. From 1964 to 1966, 49 mallard and 15 cinnamon teal nests were observed. Approximately 53 percent of the mallard nests and 46 percent of the cinnamon teal nests were on banks of sloughs or ponds. Nearly 70 percent of all mallard nests and 80 percent of cinnamon teal nests were in grasses or grasslike plants. Nests of most mallards and cinnamon teal were either completely concealed or had only one side or the top exposed. The average size of mallard broods ranged from 9.2 at hatching to 4.6 near the time of flying; for cinnamon teal the range was from 10.7 to 5.8. Estimated duck production was one per 8.1 acres in 1964 and one per 10.2 acres in 1965 in the Humboldt Bay area.

Nests were found in four ecological situations: on banks of sloughs or ponds, on dikes, in fields, and over water. Sloughs and intermittent marshes in the pastures supported stands of one or more of the following: maretail (Hippuris vulgaris), sago pondweed (Potamogeton pectinatus), alkali bulrush (Scirpus robustus), three-square bulrush (S. americanus), spike rush (Eleocharis macrostachya), saltgrass (Distichlis spicata), marsh pennywort (Hydrocotyle ranunculoides), cattail (Typha latifolia), arrow grass (Triglochin maritima), rush (Juncus spp.), water cress (Rorippa nasturtium-aquaticum) and horsetail (Equisetum spp.).

Portions of some lowland pastures held approximately six inches of temporary water early in the nesting season, and four mallard nests and two cinnamon teal nests were over water in clumps of rushes in such areas. (H.D.)

Keywords: mallards, cinnamon teals, duck nesting, productivity,
California

V-B-18

Glazener, W.C. 1946. Food habits of wild geese on the Gulf coast of Texas. *Journal of Wildlife Management* 10:322-329.

The food in the gizzards of 117 geese was separated, measured volumetrically, and identified to furnish quantitative data from birds taken in the area between Corpus Christi and Galveston Bay, Texas, from October to March, 1939-1942. Wintering geese in this area ordinarily have a regular daily feeding schedule, making one trip to the feeding ground in the early morning and another in the late afternoon with a midday rest period at a waterhole.

Food materials were shown to be entirely of plant origin, including 31 species of flowering plants and algae. More than 66 percent of the identified material was of grasses (Graminae). Rice, corn, and grain sorghums were the cultivated crops most commonly and extensively taken, and practically all of this was waste picked from the ground. Saltgrass, water cress, and panic grass were the native species most extensively consumed. Flax and winter truck crops are sometimes eaten by geese to the point that these crops may eventually require protection at times. (G.S.)

Keywords: geese, food habits, Texas Gulf coast

V-B-19

Chamberlain, J.L. 1957. An ecological study of a Gulf Coast marsh, Rockefeller Refuge, Grand Chenier, Louisiana. Ph.D. Thesis. University of Tennessee. 160 pp. (Diss. Abstr. 18:1538-B)

The purpose of the study was to describe the environment of an 86,000-acre coastal marsh, appraise the factors influencing local distribution of marsh plants, and interpret the dependency of waterfowl upon the vegetation.

Precipitation, temperature, water level, and evaporation were recorded. Soil salinity, determined from conductivity of extracted solutions, and water salinity were measured.

Heaviest rains were in the summer. Spring and fall were the driest seasons. Evaporation rates increased from winter to summer. Marsh vegetation significantly reduced evaporation. Surface soil salinities were greater and varied less than the overlying water. Seasonal variations of surface soil and water paralleled one another. Salinity was highest in early summer and in the fall and lowest in winter and early spring. There was an inverse relationship between salinities and water levels. Trends in evaporation agreed with changes in salinity. A slight vertical salinity gradient was normal in a

brackish ditch, but there was none in the shallow marsh waters. Gradients were more pronounced in canals, but the gradients were variable.

The source of marsh water was almost entirely from rainfall. Water loss was normally through surface evaporation and transpiration. Water depths were greatest inland and decreased toward the Gulf. Winds profoundly affected water levels, but tidal influence was negligible. Water levels were lowest in early fall. The pH of marsh waters was slightly alkaline, and marsh soils were nearly neutral.

A map of the marsh vegetation was compiled and fresh, brackish, and salt-marsh zones were defined. Frequency distributions of marsh plants correlated well with soil salinities. Soils of the salt-marsh were azonal; brackish and fresh-marsh soils were intrazonal. Changes in marsh plant associations reflect adjustments to soil development, salinity, and water levels.

Mallards comprised 54 percent of the wintering duck population, and blue geese constituted 92 percent of the wintering geese. The majority of the waterfowl population was in the area from late October to the following April. Waterfowl composition was different in various types of marshes.

Marsh plant utilization was determined by analysis of 1,251 gizzards from 17 species of wintering waterfowl. Differences occurred in items taken by ducks in different types of marshes. Forty-nine plants were identified from remains of food materials in the gizzards. Seeds of Cladium, Scirpus and Eleocharis were most frequently taken. It was concluded that utilization of food items depends primarily on their relative availability. (A.A.)

Keywords: coastal marsh, ecology, marsh plants, waterfowl, Louisiana

V-B-20

Chamberlain, E.B. 1959. Gulf coast marsh vegetation as food of wintering waterfowl. *Journal of Wildlife Management* 23:95-102.

The gizzard contents of seventeen species of ducks and geese were studied. Forty-nine plant species were identified. Seeds of Cladium, Scirpus, and Eleocharis were found to constitute important food sources. (J.B.)

Keywords: coastal marshes, marsh plants, waterfowl foods, U.S. Gulf coast

V-B-21

Glasgow, L.L., and H.A. Junca. 1962. Mallard foods in southwest Louisiana. Louisiana Academy of Sciences 25:63-74.

Data for this report were obtained during a study of the nutrient content of mallard foods in southwest Louisiana. The common mallard (Anas platyrhynchos platyrhyncos) is not only the most widely distributed duck in the northern hemisphere, but also the most abundant species. The mallard is the most important wild waterfowl in the hemisphere, and is the preferred duck of waterfowl hunters.

Grasses provided mallards with most of their food (98 percent) during the winter of 1960-1961 in southwestern Louisiana. The most important species were millets, fall panicum, paspalums, giant fox-tail, bagscale, and domestic rice. Smartweeds provided a reasonable amount of food, sedges a small amount, and all other plants insignificant amounts.

Animal matter, which made up less than 2 percent of the total food, was composed of snails, crustaceans, insects, spiders, clams, amphibians, fish, and leeches. (B.W.)

Keywords: mallards, marsh grasses, food habits, Louisiana

V-B-22

Glasgow, L.L., and J.L. Bardwell. 1962. Pintail and teal foods in south Louisiana. Proceedings of the sixteenth annual conference of the Southeastern Association of Game and Fish Commissioners, pp. 175-184.

Most previous waterfowl food-habits studies indicate that the sedge family is the most important contributor to duck diets on the Gulf Coast. Results of this study show that in the area sampled, the grass family is far more important than the sedge family, providing about 95 percent of the pintail food and 90 percent of the teal food. The sedge family was unimportant to pintails and was of minor importance to teals. Other plant families provided very small quantities of food.

Based on the quantities of seed found in this study, duck food producing plants are ranked in the following order.

Pintail

1. Fall panicum
2. Brownseed paspalum
3. Walter's millet
4. Bagscale grass

Teal

1. Fall panicum
2. Sprangletop
3. Flatsedge, fragrant
4. Giant foxtail

- | | |
|-------------------------------|----------------------------|
| 5. Barnyard millet | 5. Walter's millet |
| 6. <u>Paspalum acuminatum</u> | 6. Barnyard millet |
| 7. <u>Domestic rice</u> | 7. Brownseed paspalum |
| 8. Sprangletop | 8. Bagscale grass |
| 9. Smartweed, Swamp | 9. <u>Amaranthus</u> sp. |
| 10. Junglerice | 10. <u>Unknown panicum</u> |

(G.S.)

Keywords: pintails, teals, duck food habits, Louisiana

V-B-23

Junca, H.A. 1962. A quantitative study of the nutrient content of food from crops of wild mallards. M.S. Thesis, Louisiana State University, Baton Rouge. 94 pp.

A study was conducted (1) to determine the nutrient content of foods removed from the crops of wild mallards, (2) to identify these foods, (3) to compare the foods eaten by mallards with those reported in other studies from the same area, and (4) to compare the results from the chemical analyses with the dietary recommendations for domestic and semi-domestic ducks.

An analysis of 226 mallard craws, collected during the hunting season of 1960-1961, in seven areas representing the major waterfowl concentration areas of south Louisiana, showed that the Graminae family made up the largest volume and weight of total plant food, and gastropods were the most important animal food.

An analysis of variance showed that there was more variation between areas than within areas, in regard to crude protein, crude fiber, nitrogen-free extract, ash, and phosphorus. Ether extract and calcium percentages were insignificant at both the one percent and five percent levels of probability.

It appeared that most of the samples analyzed were nutritionally deficient when compared to the calculated analysis of a semi-domestic duck breeder ration. However, of the 226 ducks examined, 185 were rated good, 21 fair, 4 poor, and 16 unknown, based on the amount of fat deposition on the carcass. (A.A.)

Keywords: nutrient values, mallards, Louisiana

V-B-24

Beter, R.A. 1956. A comparative winter food habit study of dabbling ducks. M.S. Thesis, Louisiana State University, Baton Rouge. 74 pp.

A winter food habit study of 103 dabbling ducks from the brackish Lake Borgne marsh and the freshwater marsh of Pass a Loutre was made in 1956.

Analysis of gizzards from samples taken from Lake Borgne showed that the four major foods, in the order of importance, were: Ruppia maritima, Cladium jamaicense, Scirpus robustus, and Scirpus californicus.

Analysis of 39 gizzards from Pass a Loutre showed that the four major foods, in the order of importance, were: Potamogeton pusillus, Najas guadalupensis, Neretina reclinata, and C. jamaicense.

The five most important foods for dabbling ducks were found to be: R. maritima, C. jamaicense, Scirpus spp. (predominantly S. californicus), P. pusillus, and N. guadalupensis. (A.A. and B.W.)

Keywords: food habits, dabbling ducks, coastal marsh, Louisiana

V-B-25

Stieglitz, W.O. 1966. Utilization of available foods by diving ducks on Apalachee Bay, Florida. Proceedings of the twentieth annual conference, Southeastern Association of Game and Fish Commissioners, pp. 42-50.

A study designed to determine the vegetative composition and production of that portion of Apalachee Bay, Florida, included within the St. Marks National Wildlife Refuge was carried out in 1964. Gizzards and gullets of fourteen diving ducks were subsequently collected in order to correlate feeding activities with available foods. Greater scaup consumed large quantities of animal foods. Redheads consumed considerably more vegetative material than animal, and showed a predilection for shoalgrass. Shoalgrass constituted 67.9 percent of the total volume of all foods consumed by diving ducks. Turtlegrass and manateeegrass, two other species that occur commonly in the bay, apparently are of little value as waterfowl foods in this area. Vegetative production data were correlated with food habits to determine the approximate carrying capacity of the study area in waterfowl use days, and to ascertain the percentage utilization of the standing crop of vegetation by waterfowl during the 1964-65 wintering period. (A.A.)

Keywords: ducks, food habits, coastal marshes, shoalgrass, Florida

V-B-26

LaHart, D.E., and G.W. Cornwell. 1970. Habitat preference and survival of Florida duck broods. Proceedings of the twenty-fourth annual conference of the Southeastern Association of Game and Fish Commissioners, pp. 117-121.

Florida duck broods were captured and banded by nightlighting in fresh, salt, and brackish water habitats. Ducklings were most frequently observed in brackish water areas. Duckling survival, as determined by brood size observations, was lower than in other mallard subspecies. Most duckling mortality occurs immediately after hatching. Ducklings are very terrestrial, a trait that reduces exposure to an abundance of predators associated with Florida's aquatic environments.

The most productive Florida duck brood habitat is the brackish water marshes on Merritt Island and Sanibel. Needlerush (Juncus roemerianus), salt grass, and cord grass (Spartina bakeri) are characteristic emergents; spiny naiad (Najas marina) and widgeon grass (Ruppia maritima) are the common submergents. The highest concentration of Florida ducks was found in the large, brackish water impoundment immediately north of the Vehicle Assembly Building at the Kennedy Space Center on Merritt Island. (A.A. and G.S.)

Keywords: duck broods, habitat preference, coastal marshes, Florida

V-B-27

Kerwin, J.A., and L.G. Webb. 1971. Foods of ducks wintering in coastal South Carolina, 1965-1967. Proceedings of the twenty-fifth annual conference of the Southeastern Association of Game and Fish Commissioners, pp. 223-245.

During the wintering seasons of 1965-1967, 706 waterfowl gizzards were collected and subsequent food habit studies were made. The collections represented 14 species of waterfowl (9 species of dabblers and 5 species of divers). Six hundred and five collections constituted the dabbling duck sample and 101 gizzards represented the diving duck sample. The most important foods consumed were from fresh and slightly brackish water habitats. Seeds of marsh plants and vegetative fragments and seeds of pondweeds were the primary foods consumed. Animal foods in the diet were not considered important. The most important food consumed by volume by dabbling ducks was Najas guadalupensis. The most important food consumed by volume by diving ducks was Brasenia schreberi. The plant most frequently used by dabblers was Scirpus validus, while the plant most frequently used by diving ducks was Brasenia schreberi. (A.A.)

Keywords: ducks, food preference, South Carolina

V-B-28

Conrad, W.B., Jr. 1965. A food habits study of ducks wintering on the lower Pee Dee and Waccamaw rivers, Georgetown, South Carolina. Proceedings of the Nineteenth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 93-98.

The study was made principally in the Pee Dee Management Area, South Carolina Wildlife Resources Department, but it also included some surrounding privately owned lands on the lower Pee Dee and Waccamaw rivers in Georgetown County, approximately 15 miles northeast of Georgetown. The most important ducks wintering along the lower Pee Dee and Waccamaw rivers were mallards, green-winged teals, pintails, black ducks, and wood ducks. The foods most preferred by ducks in this area were aneilema, big leaf tearthumb, swamp smartweed, arrow arum berries, square stem spikerush, and soft-stem bulrush. Aneilema was found to be an excellent duck food in this area. Further investigation of the importance of aneilema as a waterfowl food should be made to determine (1) nutritional value, (2) usage in other locations, and (3) possibilities of introduction into waterfowl areas where absent. Plant surveys revealed that good duck food plants were much more abundant in managed impoundments than in tidal marshes. Ducks were found to use diked impoundments more extensively than undiked marshes. Diking, water manipulation, and prescribed burning of tidal marshes will result in increased production of duck foods. This study illustrates the value of local food habits studies in contrast to national or continental studies. (G.S.)

Keywords: food habits, ducks, South Carolina

V-B-29

McGilorey, F.B. 1964. Effects of elimination of alligatorweed on certain aquatic plants and the value of these plants as waterfowl foods. Proceedings of the Eighteenth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 73-79.

The effects of elimination of alligatorweed (Alternanthera philoxeroides) by granular silvex on the abundance of 12 species of aquatic plants were studied in the Santee National Wildlife Refuge, Lake Marion, South Carolina, from 1961 to 1964. Three hundred and sixty duck stomachs collected from hunters during the 1961 hunting season were examined to determine the importance of these 12 species as waterfowl food.

Five of the 12 plant species were important food items for ducks. In order of importance, they were: southern cutgrass (12 percent of total volume); hydrochloa (10 percent); buttonbush (nearly 6 percent); annual spikerush (nearly 4 percent); and swamp smartweed (3.7 percent). Squarestem spikerush was important to pintail and mallard, and Cyperus spp. was important to black duck and green-winged teal.

As so often happens when attempting to manipulate waterfowl habitat, especially in the Southeast, alligatorweed control provided mixed blessings. Valuable waterfowl food plants, such as Cyperus spp. and annual spikerush, increased temporarily. It appeared, however, that over a period of several years the benefits of alligatorweed control to waterfowl were outweighed by increased abundance of maidencane. (G.S.)

Keywords: alligatorweed, waterfowl foods, aquatic plants, coastal marshes, South Carolina

V-B-30

Quay, T.L., and T.S. Critcher. 1962. Food habits of waterfowl in Currituck Sound, North Carolina. Proceedings of the Sixteenth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 200-209.

The food contents of 326 gizzards from 15 species of waterfowl collected on Currituck Sound between 1947 and 1952 were analyzed in detail by the aggregate percentage method. The collection period was a time of generally low and fluctuating waterfowl populations on the Sound. Percent frequency and percent volume results are presented for 122 diving ducks (six species), 75 ruddy ducks, 97 dabbling ducks (six species), 17 Canada geese, and 15 coots, both in groups and by species. Plant foods composed 97 percent of the total.

Potamogeton, Ruppia, and Najas were the overwhelmingly important foods for all groups, totaling about 80 percent by volume for the entire sample (72 percent identified and probably most of the 11 percent unidentified vegetative material). Nevertheless, the 7 commonest species--canvasback, redhead, ruddy duck, American widgeon, black duck, pintail, and green-winged teal--each showed distinctive individual differences in types and percentages of foods taken. Vallisneria, now present in the Sound in good supply, did not appear in any of the gizzards examined and very possibly was relatively rare or spotty in the Sound during the 1947-1952 period. (A.A.)

Keywords: waterfowl, food habits, North Carolina

V-B-31

Florschütz, O., Jr. 1972. The importance of Eurasian milfoil (Myriophyllum spicatum) as a waterfowl food. Proceedings of the Twenty-sixth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp.189-193.

The primary objectives of the study were to determine and document waterfowl use of Eurasian milfoil in the vicinity of a new outbreak

near Back Bay and Mackay Island National Wildlife Refuges in Virginia and North Carolina.

Digestive tracts were collected in the vicinity of Back Bay, Virginia, and Currituck Sound, North Carolina, during the 1968-69, 1969-70 and 1970-71 hunting seasons. Examinations of 170 waterfowl digestive tract contents included 27 Canada geese, 74 dabbling ducks of six species, 38 diving ducks of four species and 31 coots. Analysis revealed that: 71.8 percent contained Eurasian milfoil, 84.7 percent held other foods, 13.5 percent had milfoil as the only food, 27.1 percent had other foods but no milfoil, and 1.8 percent had no food.

Quantitative analysis showed that the content of all digestive tracts was 43.9 percent grit, 18.3 percent Eurasian milfoil, and 37.8 percent other foods. When considering food only in the 170 tracts of 12 waterfowl species, milfoil comprised approximately one-third of the volume. Highest milfoil use was noted in scaups, followed in order by gadwalls, widgeons, Canada geese, redheads, pintails, green-winged teals, ruddy ducks, black ducks, coots, mallards and canvasbacks. Natural foods led the "other foods" category and were headed by pondweeds, widgeon-grass, southern naiad, wild celery plants and seeds, and seeds from the family Cyperaceae. (A.A.)

Keywords: Eurasian milfoil, waterfowl food, Virginia

V-B-32

Stotts, V.D., and D.E. Davis. 1960. The black duck in the Chesapeake Bay of Maryland: breeding behavior and biology. *Chesapeake Science* 1:127-154.

The breeding behavior and biology of black ducks, Anas rubripes, were observed from 1953-1958 on the upper Eastern Shore of Chesapeake Bay in Maryland. Ducks were trapped, banded, and marked during the study in an essentially estuarine habitat, which was frost-free from mid-April to early November. The general habitat adjoining the bay consisted of cultivated fields, pine woods with dense underbrush, extensive marshes in some areas, and duck blinds.

Resident black ducks began to pair in the late summer, and the pairing activity reached a peak in early April just before the height of the breeding season. Few if any young were observed to pair in the early fall. In the spring the male defended a territory for each clutch, generally using some promontory along the shore. The male remained nearby while the female built her nest, gradually deserting his mate during incubation. Eventually the pairing bond disappeared, although some males probably paired again with renesting hens.

Females renested one or more times when the eggs were destroyed or even when the ducklings disappeared on the first day after hatching. At least eight out of 51 marked ducks were known to have renested.

The dates of first laying ranged from March 9 to March 27. The nesting peaks occurred about April 20. The first hatching occurred in early April; the last in early August. The date by which 50 percent of the nests were started was significantly earlier in 1953 than in 1957 or 1958, but no other differences were significant. Comparison of the peaks of hatching and of laying showed that in 1958 a loss of early clutches occurred.

Nests were built most extensively in woods, less so in fields and marshes, and markedly less on duck blinds. They were constructed from adjacent material (leaves, grass, twigs, pine needles) in shallow basins, which were occasionally used by renesting females. Usually the nest site was covered by honeysuckle, poison ivy, brush, or grasses. Spacing between nests was determined by available cover; sometimes they were placed within a few feet of each other. The density ranged from 0.6 to 15.2 nests per acre.

The average number of eggs in a clutch declined from 10.9 to 7.5 during the season (360 clutches). Young females laid smaller average clutches (9.2) than adults (9.7). Primary clutches were larger (9.1) than secondary clutches (8.1) for the same females. The incubation period averaged 26.2 days (51 clutches). Neither size of clutch nor season had a significant effect on incubation period. About 5.6 percent of the eggs did not hatch.

The fate of nesting was determined for 574 nests. During the six years, 38.0 percent hatched at least one egg, 11.5 percent were abandoned, and 50.0 percent were destroyed (34.0 percent by crows). Although complete and incomplete clutches were equally susceptible to predation, over half (51.8 percent) of the destruction of complete clutches occurred in the first week of incubation. An average of 9.6 percent of eggs in successful clutches was taken by crows.

Estimations of production indicated that 100 females would raise 510 young to flying age and that the population in the area would decline if the mortality rate of females from flying age to breeding exceeded 78 percent. (A.A.)

Keywords: black duck, coastal marsh, nesting habits, productivity, Maryland

V-B-33

Roth, R.R., J.D. Newsom, T. Joanen, and L.L. McNease. 1972. The daily and seasonal behavior patterns of the clapper rail (Rallus longirostris) in the Louisiana coastal marshes. Proceedings of the Twenty-sixth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 136-147.

The objectives of this study were to determine: (1) daily and seasonal movements and activity patterns of clapper rails in Louisiana coastal marshes, and (2) their seasonal food habits in different habitat types. The authors constructed 12 miniature radio transmitters and attached them to clapper rails to achieve the first objective of this study. The period of contact for the instrumented rails ranged from 7 to 47 days. The results of the radio telemetry study indicated that Louisiana clapper rails have an average minimum home range of 168 yards along canals and tidal ditches in the summer and 533 yards in winter. One instrumented rail was preyed upon by a mink. The food habits study on clapper rails collected in the salt and brackish marshes indicated that the bulk of their diet during the summer consists of fiddler crabs. In the winter, fiddler crabs become less important while crayfish and snails become more important. (A.A.)

Keywords: clapper rail, food habits, coastal marshes, Louisiana

V-B-34

Bateman, H.A., Jr. 1965. Clapper rail (Rallus longirostris) studies on Grand Terre Island, Jefferson Parish, Louisiana. Louisiana Wild Life and Fisheries Commission, Baton Rouge. 144 pp.

The objectives of the study were to investigate and develop methods of trapping, field marking, and external sexing and aging of clapper rails. Fall food habits, internal parasites, censusing, and nesting were also investigated.

Analysis of gizzard contents revealed that the clapper rail's diet in the fall consists largely of small crabs and snails. Nesting observations revealed that the nesting ecology of clapper rails in Louisiana is probably similar to that of clapper rails in other states. (A.A., modified)

Keywords: clapper rails, food habits, Louisiana

V-B-35

Oney, J. 1951. Food habits of the clapper rail in Georgia. *Journal of Wildlife Management* 15:106-107.

The report summarizes findings from 669 clapper rail, Rallus longirostris, gizzards collected in coastal Georgia during October and November 1947. Most specimens were probably of the Wayne's clapper rail subspecies (Rallus l. waynei) and very probably some individuals of the northern clapper rail (Rallus l. crepitans). The winter range of the latter subspecies extends into Georgia.

Sixty-one kinds of food were found in the clapper rails' gizzards, but most of these foods occurred in small quantities--traces of fractions of one percent. Ten of the 61 foods constituted 97 percent volumetrically of the whole diet. The clapper rail's diet in Georgia during the late fall was found to be composed almost wholly of animal foods. Cordgrasses (Spartina) are the chief plant components of the marshes, yet their seeds constituted only traces in this series.

Crabs of several species were found to be common in the tidal marshes and the principal source of the rail's food--totaling nearly 75 percent. The square-backed fiddler crabs (Sesarma) occur typically in soft mud along the sloughs and creeks and are more inclined to be solitary in habit than the common fiddler crabs (Uca). The latter are found abundantly on higher ground in the marsh. The square-backs seem to be the less abundant of these two, yet the data show that they are eaten to a much greater extent. Crabs of the genera Eurytium and Panopeus are fairly abundant in the marsh. The latter seems to be the less common of the two.

The snail Littorina irrorata is common over all of the marsh. It is ingested whole by the rails. Insects, though plentiful in the marshes and taken commonly in small amounts, would be of little apparent importance to the clapper rail except for the cutworm moth, family Phalaenidae. Spiders and small fish constitute a small part of the diet. (G.S.)

Keywords: clapper rail, food habits, tidal marshes, Georgia

V-B-36

Adams, D.A., and T.L. Quay. 1958. Ecology of the clapper rail in southeastern North Carolina. *Journal of Wildlife Management* 22:149-156.

The breeding biology, seasonal populations, and behavior of the clapper rail were studied at Southport, N.C., in 1955-1956. The wintering population was small, and confined primarily to the mixed grass and grass-shrub communities at the more elevated fringes of

the marsh. Twenty-three of the 30 nests found were in Spartina alterniflora growths of medium height (2-4 feet). The mean number of eggs per clutch was 10.5 ± 0.29 . Continuous parental care of the young lasted 5 or 6 weeks. Change from chick to adult call notes began at 7 weeks. The young started flying when 9 or 10 weeks old, by which time they were becoming indistinguishable externally from adults. A weekly index to the age of immature rails was developed and is described. Nesting success was 42 percent, with an average production of nine chicks per successful nest. Local movements of the rails and trapping success were correlated with the rhythm and height of the tides. Fall migration of clapper rails through and from southeastern North Carolina apparently occurs in September and early October. Banding recoveries (4 percent) suggest that part of the local population may be nonmigratory. The juvenile-adult ratios of the summer (trapped) and fall (shot) populations were approximately 4:1. The clapper rail is not heavily hunted in North Carolina. (Author's summary)

Keywords: ecology, clapper rail, food habits, North Carolina

V-B-37

Meanley, B. 1965. Early fall food and habitat of the sora in the Patuxent River Marsh, Maryland. *Chesapeake Science* 6:235-237.

This study attempts to relate foods and feeding behavior of the sora to habitat in the Patuxent River marsh, Maryland.

The freshwater tidal marsh of the Patuxent is the chief concentration area of migrant soras in the Maryland part of the Chesapeake Bay system. Soras first arrive during early August, reach the peak of migration in late August and early September, and by late October most of these birds have moved southward. The peak population coincides with maximum seed availability in the marsh.

In the Patuxent marsh, soras feed mainly on rather large seeds, which are produced in great quantity; namely, tearthumbs, dotted smartweed, wild rice, and Walter millet. Competition from other birds, particularly the red-winged blackbird, limits the availability of certain foods to the sora. Because of this, the abundant supply of wild rice seed in Reed marsh is consumed before it matures. The fact that many wild rice seeds found in sora stomachs were still green indicates they were stripped from the plants.

While some 50 different food items were found in the 241 sora stomachs examined, only a dozen were represented by more than one percent of volume. Four items--halberdleaf tearthumb, Walter millet, dotted smartweed, and arrowleaf tearthumb--comprised nearly 80 percent by volume. The same four items also were taken more frequently than any other foods.

Insects were shown to be of minor importance in the Patuxent sample, constituting only 5 percent of the total food. (H.D.)

Keywords: birds, food habits, coastal marsh, Maryland

V-B-38

Johnston, R.F. 1956. Population structure in salt marsh song sparrows; part I: environment and annual cycle. Condor 58:24-44.

A population study of song sparrows, Melospiza melodia samuelis, was conducted from 1950 to 1955 on San Pablo marsh, California. A total of 287 individuals were color-banded.

San Pablo marsh is a typical San Francisco Bay salt marsh, grown to a Spartina association on lower levels and a Salicornia association on higher ground. The tidal range is -2.5 to 9.0 feet; mean higher high water is 5.8 feet.

The most important food of the song sparrow is the invertebrate fauna associated with marsh vegetation. Factors influencing the initiation of breeding include the photo period, temperature of the preceding three months, and the amount and distribution of the winter rainfall. These factors also affect the amount and quality of the sparrow's food supply. (B.W.)

Keywords: sparrows, salt marshes, population structure, San Francisco Bay

V-B-39

Johnston, R.F. 1956. Population structure in salt marsh song sparrows; part II: density, age structure, and maintenance. Condor 58:254-272.

On the study plot on San Pablo marsh, song sparrows in a year of medium density numbered approximately one pair per acre. Along the sloughs the density ranged from six to ten pair per acre, depending on the absolute number of birds on the marsh and the complexity of the vegetation available. Density was found to vary directly in relation to the preceding year's productivity.

Mortality factors include rodent predation, high tide water, death of or desertion by the adults, infertility and embryonic death, and storms.

Those aspects of the population that favor a strong isolation, a high population density, and the existence of habitat selection by the

birds all favor the maintenance of the integrity and distinctness of the population of song sparrows on the salt marsh. (B.W.)

Keywords: sparrows, salt marshes, population structure, San Francisco Bay

V-B-40

Post, W. 1974. Functional analysis of space-related behavior in the seaside sparrow. *Ecology* 55:564-575.

This paper compares seaside sparrow (*Ammodramus maritimus*) populations nesting in two dispersion patterns: territories and grouped territories. Territories, found in altered (ditched) salt marshes, were large, all-purpose activity spaces. Grouped territories, found in unaltered salt marshes, were small activity spaces from which birds made distant foraging flights.

Among the factors influencing the grouped territory spatial pattern, the most important were nest site availability and lack of predation. A scarcity of nest sites in the unaltered habitat appeared to require the birds to nest close together, while such aggregation was made possible by scarcity of ground predators. The territorial pattern was thought to be influenced by low population density, low food availability, and sufficiency of nest sites.

The amount of time that birds spent foraging, singing, and resting did not differ between spatial patterns, nor did the diurnal pattern of these activities. Birds on grouped territories spent more time in aggression than did birds on territories.

The breeding success of birds found in the two dispersion patterns did not differ. The rate of delivery of food to the nest was also the same, although birds on territories flew twice as far to gather food for their nests.

The results suggest that both spatial patterns are equally successful for the given conditions. Because of the variability of habitat, it is doubtful that the space-related behavior of the seaside sparrow acts to limit population size. (A.A.)

Keywords: sparrows, salt marshes, behavior patterns

V-B-41

Kale, H.W. 1964. Food of the long-billed marsh wren, Telmatodytes palustris griseus, in the salt marshes of Sapelo Island, Georgia. Oriole 29(4):47-66.

This study investigated the ecology and bioenergetics of the long-billed marsh wren, Telmatodytes palustris griseus, in the salt marshes of Sapelo Island, Georgia. Stomachs of 195 adult, immature, and nesting wrens were analyzed for food items. T. p. griseus feeds upon animals at three different trophic levels: herbivores (21 species), predators (30 species), and detritus feeders (16 species).

The marsh wren plays a very minor role in the detritus food chain of the salt marsh ecosystem. It is primarily a secondary and tertiary consumer within the grazing food chain and thus may be a major factor in the control of the secondary consumers among the arthropods. (B.W.)

Keywords: long-billed marsh wren, coastal marshes, Georgia

V-B-42

Kale, H.W. 1967. Water sources of the long-billed marsh wren in Georgia salt marshes. Auk 84:589-591.

A study was conducted to determine whether marsh wrens can use estuarine water as a water source. Adult marsh wrens were kept in cages and provided at different times with estuarine water, fresh water, or no water. Each wren was provided daily with several grams of meal worm larvae and a mixture of fish, ground beef, liver, wild game bird food, and Pabulum. Wrens provided with estuarine water or no water stopped eating the mixture and increased their consumption of meal worms. There was no change in the feeding behavior of wrens provided with fresh water. The results are not conclusive, but evidence strongly suggests that wrens do not drink estuarine water. The marsh wren apparently follows the pattern characteristic of insectivorous birds in arid regions; i.e., obtaining water needed from highly succulent food. (B.W.)

Keywords: long-billed marsh wren, salt marshes, Georgia

V-B-43

White, M., and S.W. Harris, 1966. Winter occurrence, foods, and habitat use of snipe in northwest California. Journal of Wildlife Management 30:23-24.

Occurrence, food habits, and habitat use of the wintering Wilson snipe (Capella gallinago) population in the Humboldt Bay region of northwest California were investigated from September 1961 until

April 1963. The two study areas included salt marsh and upland and lowland dairy pastures, the main habitat types used by snipe in this large wintering area. Snipe arrived during the first week of October, and numbers increased to a yearly maximum in mid-November, representing fall migration. Shortly thereafter numbers declined considerably and then increased to one or more secondary peaks in December or later. During the winter, snipe occurrence in the study areas was variable. No well-defined increase in the population occurred during the period of spring migration. After March, numbers declined until the last snipe were seen in mid-April. Terrestrial insects (mostly beetles), seeds, crustaceans, and land snails were the most important food items. Food habit evaluation was complicated because the animal material was finely ground and there was a large amount of unrecognizable plant fibers which the snipe may have picked up incidentally while probing for food animals. Most feeding occurred in upland areas where foods were abundant. Aquatic and semi-aquatic foods were much less important than was indicated in previous studies. Lowland pastures and salt marsh islands were little used as feeding areas, although potential food was abundant. Salt marsh islands were much used for loafing and preening. Both pastures and salt marshes provided closely cropped vegetation, a condition favorable to use by snipe. (A.A.)

Keywords: snipe, food habits, habitat use, California

V-B-44

Whitehead, C.J., Jr. 1962. Foods and feeding habits of the common snipe (Capella gallinago delicata) in Cameron Parish, Louisiana, with ecological notes and a discussion of methods of sexing and aging. M.S. Thesis, Louisiana State University, Baton Rouge. 200 pp.

Analysis of gizzard contents revealed that the diet of snipe consists of both plants and animals. The most important food items were plant debris, beetles, fly larvae, snails, sawgrass, sesbania, and buckbrush. (A.A., modified)

Keywords: common snipe, food habits, Louisiana

V-B-45

Meanly, B., and J.S. Webb. 1963. Nesting ecology and reproductive rate of the red-winged blackbird in tidal marshes of the upper Chesapeake Bay region. Chesapeake Science 4:90-100.

The nesting ecology and reproductive rate of the polygynous red-winged blackbird, Agelaius phoeniceus, were studied in the tidal marshes of Maryland during the period of 1958 through 1961. Sixteen

nesting colonies were located in six major marsh communities of the eastern shore and were visited approximately twice a week from late April to mid-August.

The average clutch size for 537 clutches was 3.3 eggs, with a range of 2 to 5 eggs. The ratio of territorial males to nesting females was 1:1.9. There was direct evidence of double broods by four females. The average number of young produced was 4.2 per breeding female, or 8.1 per breeding male.

Nesting success for the total of 675 active nests was 57 percent, with a range from 38 percent to 69 percent in the colonies. Robust plants that held constant form throughout the nesting season supported 95 percent of the nests, and the success of these nests was 58 percent; in contrast, non-robust plants supported only 5 percent of the nests, and the success of this group of nests was only 26 percent. Nesting success varied with height from ground: 45 percent for nests less than 2 feet from the ground, 55 percent for those 2 to 4 feet, and 62 percent for those more than 4 feet. Histories of 749 nests were summarized by stages: 749 newly built, 675 with eggs, 424 with nestlings, and 388 with fledging young. (A.A.)

Keywords: nesting ecology, red-winged blackbird, tidal marshes, Chesapeake Bay

V-B-46

Henny, C.J., and V.D. Stotts. 1975. Osprey productivity during the mid-1950s in a portion of Chesapeake Bay. *Chesapeake Science* 16:219-220.

While offshore duck blinds in Chesapeake Bay were being surveyed intensively in the mid-1950s to determine use by nesting ducks, information was also collected on osprey nesting. The number of young fledged per active nest was 1.10, which is about the middle of the standard (0.95 to 1.30) necessary to maintain a stable population. Healthy populations consist of 5 to 10 percent of the 2-year-old age class.

The authors conclude that the observed production rate along the upper eastern shore of Chesapeake Bay in the mid-1950s appeared to be normal or near-normal, based on a small sample. (B.W.)

Keywords: ospreys, productivity, Chesapeake Bay

V-B-47

Henny, C.J., M.M. Smith, and V.D. Stotts. 1974. The 1973 distribution and abundance of breeding ospreys in the Chesapeake Bay. *Chesapeake Science* 15:125-133.

An aerial survey in association with several intensive ground surveys yielded the first estimate of the size of the osprey (Pandion haliaetus carolinensis) nesting population in Chesapeake Bay. The 1973 population was estimated at 1,450 + 30 pairs, of which 713 were on the western shore and 737 on the eastern shore. A small percentage of nonbreeders (possibly 2 to 5 percent) may be included in this estimate. Only 31.7 percent of the population was nesting in trees; the remaining birds utilized duck blinds (28.7 percent), channel markers (21.8 percent), and miscellaneous man-made structures (17.8 percent). The geographical distribution of nesting ospreys has quite likely changed during the last several decades as suitable artificial nesting sites have become more available. Furthermore, limited evidence suggests that birds nesting on the man-made sites were more successful than those nesting in trees. This study provides a basis for monitoring future changes in numbers and distribution. (A.A.)

Keywords: ospreys, nesting ecology, Chesapeake Bay

V-B-48

Jemison, E.S., and R.H. Chabreck. 1962. Winter barn owl foods in a Louisiana coastal marsh. *Wilson Bulletin* 74:95-96.

The barn owl (Tyto alba) is usually associated with agricultural or wooded areas, but has been encountered frequently in the coastal marshes of Louisiana. A study was conducted in 1961 in the Marsh Island Wildlife Refuge, 85,000 acres of sub-delta marsh that lie in the Gulf of Mexico just offshore of south central Louisiana. The dominant vegetation is Spartina patens, Scirpus olneyi, and Juncus roemerianus.

Analysis of pellets revealed remnants of vertebrate animals--97.5 percent rice rats (Oryzomys palustris) and 2.5 percent small passerine birds. Since the rice rat was the only small mammal found in the pellets and during the trapping operation, it is probable that it was the only small mammal present on the island in significant numbers. (B.W.)

Keywords: barn owl, winter foods, coastal marshes, Louisiana

V-B-49

Williams, L.E., Jr., and L.L. Martin. 1970. Nesting populations of brown pelicans in Florida. Proceedings of the Twenty-Fourth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 154-169.

Aerial searches and mail questionnaires revealed 22 active nesting colonies of brown pelicans (Pelecanus occidentalis) on small islands close to shore off the Florida peninsula and a number of additional colonies in Florida Bay and the Florida Keys between 1968 and 1970. The same nesting islands were occupied in most years. Nesting took place during late winter and spring in Florida Bay and during late spring and summer in colonies off the peninsula. The maximum numbers of nests counted during 1968, 1969, and 1970 was 6,926, 6,100, and 7,690, respectively. This represents a conservative estimate of 12,200 to 15,380 brown pelicans nesting during the period of the census. Prebreeding age classes were not counted.

Most colonies were in trees on small natural islands. One colony on a spoil island in Anclote Sound was on the ground. At least three other colonies were on wholly or partially filled islands. Trees used for nesting had strong outer branches that allowed unimpeded access to and from nests. Black mangrove (Avicennia nitida) was the principal tree used on the east coast and red mangrove (Rhizophora mangle) was the species most often used for nesting on the Gulf coast, although black mangrove was important on the Gulf coast also. The number of colonies and variety of nesting cover used were greater in the Gulf.

The adult population has apparently remained stable in Florida during the past three years. The census techniques used in this survey are not sensitive enough to reveal small changes in population size; therefore, this survey gives no indication whether reproduction has been sufficient to sustain this population size over a long period of time. (A.A.)

Keywords: brown pelicans, nesting populations, Florida

C. Mammals

V-C-1

Paradiso, J.L., and C.O. Handley, Jr. 1965. Checklist of mammals of Assateague Island. Chesapeake Science 6:167-171.

Twenty-five mammal species are listed from Assateague Island, off the Atlantic coast of Maryland and Virginia. Eleven are native land species, six are feral or semi-feral forms introduced by

man, and eight are marine. The land species are discussed in relation to their habitats, which include coastal dunes, fresh- and saltwater marshes, swamps and forests. (A.A.)

Keywords: mammals, feral mammals' habitats, coastal marsh, estuaries, Maryland-Virginia coast

V-C-2

Wilson, K.A. 1968. Fur production on southeastern coastal marshes. Pages 149-162 in J.D. Newsom, ed., Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge.

Most of the 6,832,239 acres of coastal marshes in the states bordering the Gulf and south Atlantic coasts had not been managed for furbearers prior to 1900 and were generally considered wastelands. Increased fur values inspired landowners to manage marshes for muskrat. No effort has been made to manage raccoon, mink, or otter except through trapping regulations.

Nutria, muskrat, raccoon, mink, and otter are valuable furbearers. In 1966, the estimated value of fur and meat harvested from marshes in the coastal states was \$5 million, and annual values range from \$3-\$15 million. Louisiana leads all other states in fur production.

The greatest natural causes of habitat destruction are hurricanes and droughts. Acres of marsh are destroyed also by man's ditching and draining, dredging and filling, oil exploration, mining, water pollution, and road construction. (B.W.)

Keywords: fur production, coastal marshes, U.S. Gulf and south Atlantic coasts

V-C-3

Palmisano, A.W. 1972. The distribution and abundance of muskrats (*Ordatra* [sic.] *zibethicus*) in relation to vegetative types in Louisiana coastal marshes. Proceedings of the Twenty-sixth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 160-177.

Muskrats lead all other North American wild furbearers in numbers caught and in the overall value of their pelts. The northern Gulf coast marshes produce a major portion of the national catch, and during peak years, approximately 50 percent of all muskrat skins produced in the United States come from these marshes. Since muskrats are widespread over practically all of the United States and Canada, they are obviously capable of adapting and thriving in many different environments. Even

within a limited geographic area, however, subtle differences in habitats are important to muskrat distribution and abundance. Recent interest in the estuarine environment has prompted a comprehensive evaluation of the wetland habitat in coastal Louisiana. The report is an outgrowth of that study and attempts to classify the marsh vegetative types and their potential role in the production of muskrats.

Muskrat populations were significantly higher in brackish marshes than in the other types surveyed. An average of 72.6 percent of the total muskrat houses counted were located in brackish marsh. Although the percentage values were approximately equal for southeastern and southwestern Louisiana, population densities were much higher in the southeast. Saline marshes in the southeast contained populations approximately equal to the overall average density. In the southwest, however, saline marshes appeared to be very poor muskrat habitat, possibly because of their well-drained nature. Intermediate transition marshes had below-average population densities, but were average or high in restricted areas adjacent to the brackish type. Fresh marshes exhibited the lowest muskrat population densities of any of the types surveyed. Although they comprised 31.4 percent of the total area studied, they averaged only 4.1 percent of the muskrat houses counted.

Highest house counts occurred in February when water levels were generally high, temperature was low, and the spring breeding season begins. These factors are undoubtedly responsible for the increase in the number of muskrat houses observed at this time. Tunneling, either in spoil levees or in the peat soils, was not considered a significant factor in calculating muskrat populations in the coastal marsh area. In other situations, however, this factor could significantly alter population estimates.

Catch figures indicate that the average production of muskrats can be estimated by multiplying the number of active houses by three. The average catch ranged from 2.67 to 3.41 muskrats per house and averaged 3.19. Earlier studies using quotas of estimated total muskrat populations yielded similar results. Body measurements revealed that tail length was closely correlated with the size of the muskrat and that tails alone could be used to estimate the size composition of a given muskrat population. (G.S.)

Keywords: muskrats, marsh vegetation, coastal marshes, Louisiana

V-C-4

O'Neil, T. 1949. The muskrat in the Louisiana coastal marshes. Louisiana Department of Wildlife and Fisheries, New Orleans. 152 pp.

The findings presented in this book are the result of studies made by the author during a five-year period from 1940 to 1945. The major portion of the book is a study of the ecology, population

trends and methods of managing and producing muskrats on the Louisiana coast.

A description of the Louisiana marshes is included. The book contains information on the delta marshes, natural levees, ponds, and the various zones. The natural history of the muskrat is presented, including geographic distribution, reproduction, parasites and population, food habits, and usage of various plant species by muskrats.

The publication analyzes and correlates the many factors influencing the productivity and ecology of the muskrat. The author points out that Scirpus olneyi, three-cornered grass, is the most important plant in maintaining the muskrat population. It is used in house construction and as a major food item. (B.W.)

Keywords: muskrats, coastal marshes, Louisiana

V-C-5

Milne, R.C., and T.L. Quay. 1966. The foods and feeding habits of the nutria on Hatteras Island, North Carolina. Proceedings of the Twentieth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 112-123.

Hatteras Island, in the Cape Hatteras National Seashore Recreational Area, is the longest and easternmost of the barrier islands that constitute the outer banks of North Carolina. The field research for the study was conducted at various times between the summer of 1956 and the spring of 1963. Five study regions were chosen as representing a wide variety of marsh habitats. A partial census of plant species within the study regions was made to evaluate nutria foods. Specific areas of investigation centered on feeding methods, plant species utilized for food (numerous tables cover summer and winter periods), and droppings analyses. (G.S.)

Keywords: feeding habits, nutria, North Carolina

V-C-6

Garner, K.M. 1962. Nutritive values and digestibility of some wetland wildlife foods in Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge. 90 pp.

A study was conducted in south Louisiana to determine the seasonal digestibility of common cattail (Typha latifolia) and alligator grass (Alternanthera philoxeroides) by the nutria (Myocastor coypus) and to determine the nutritive value of these species to that animal.

Common cattail was found to be a slightly better source of energy, except during the July trial, and alligator grass was the better source of crude protein in all trials.

Fifty-seven wetland plants, most of which were known to be used as food by the nutria, were quantitatively analyzed for crude protein, fat, carbohydrates, calcium, and phosphorus. As a group, the floating aquatics were found to be the best potential source of crude protein. (A.A., modified)

Keywords: nutritive values, wildlife foods, marsh grasses, nutria, Louisiana

V-C-7

Ivey, R.D. 1948. Raccoon in the salt marshes of northeastern Florida. *Journal of Mammology* 29:290-291.

The article presents the findings of a study conducted from September 1946 to April 1947. The area investigated, between St. Augustine and Ponte Vendra Beach, exhibits typical ecological conditions as found on that part of the Florida east coast. A barrier island, consisting of beach, dunes, scrub, hummock, cypress swamp, hardwood swamp, fresh water marsh, and pine flatwoods, is separated from the mainland by brackish or salty tidal marsh.

The raccoon was found in a number of habitats. Salt marsh raccoons take advantage of the abundant food supply exposed on mud banks, beaches and stream bottoms at low tide. The food consists primarily of crustaceans and mollusks. During high tide, the animals use special low, flat areas of Spartina alterniflora and Juncus roemerianus. The nesting and bedding places were also found in this area. (B.W.)

Keywords: racoons, salt marshes, food habits, Florida

V-C-8

Shure, D.J. 1970. Ecological relationships of small mammals in a New Jersey barrier beach habitat. *Journal of Mammology* 51:267-278.

Studies were conducted at Island Beach State Park, New Jersey, to determine the distributional patterns and movements of small animals in a barrier beach habitat. Species captured were Peromyscus leucopus, Microtus pennsylvanicus, Zapus hudsonius, Mus musculus, and Sorex cinereus. Most barrier beach communities contained a greater abundance of small mammals than reported from the New Jersey mainland. The distribution of small mammals at Island Beach was related to the topographically controlled pattern of environment and vegetation.

Few mice foraged in the sparse cover of the highest dune zone elevations. Peromyscus leucopus occupied the thicket and woodland habitat of the more protected dune areas, while Microtus pensylvanicus dominated those hydric bayshore habitats containing dense herbaceous cover. Both habitat orientation and interspecific interactions may be involved in the distributional pattern of M. pensylvanicus and P. leucopus. Succession in dune zone locations results in an increased abundance of P. leucopus as shrub cover increased during seral stages. Recapture distance of P. leucopus were inversely related to both population size and density of shrub cover. Zapus hudsonius, which was associated with moist habitats of the barrier beach, had either large or unstable home ranges. (A.A.modified)

Keywords: mammals, barrier beach habitat, ecological relationships, New Jersey

V-C-9

Sharp, H.F., Jr. 1967. Food ecology of the rice rat, Oryzomys palustris (Harlan), in a Georgia salt marsh. Journal of Mammalogy 48:557-563.

Examination of 22 stomachs of rice rats taken in summer and fall indicated a predominance of animal food, chiefly insects and small crabs, although plant remains were present in several stomachs. Predation on eggs and young of marsh wrens was known to occur. Individuals reared in the laboratory from nestlings taken from a Georgia salt marsh preferred foods of an animal source and made greater weight gains when animal material constituted all or part of the diet. While captives were able to assimilate both plant and animal food efficiently

$$\frac{(\text{ingested energy} - \text{fecal energy})}{\text{ingested energy}} \times 100 = 88-95 \text{ percent}),$$

they ingested more calories when animal food was offered. A daily intake level of 0.15 kcal/kcal body tissue was required to maintain body weight in the laboratory; ingestion rates above this level resulted in weight gains. It is concluded that during the summer months the trophic niche of the rice rat in the salt marsh ecosystem is that of a carnivore. (A.A.)

Keywords: rice rat, salt marshes, food ecology, Georgia

V-C-10

Fisler, G.F. 1961. Behavior of salt-marsh Microtus during winter high tides. Journal of Mammalogy 42:37-43.

The populations of Microtus californicus inhabiting the salt marshes of the San Francisco Bay region are subjected to daily high tides, but

extremely high tides, which completely submerge most vegetation and thus force mice from cover, are encountered only in winter. The mice are in considerable danger of drowning and avian predation at this time. During these high tides, mice hide in what emergent vegetation remains, swimming freely on the water surface as little as possible. However, swimming and diving abilities are well developed. Evidence presented shows that Microtus usually remain on their home ranges during and after these very high tides, and it is concluded that only the rare, combined effects of wind, rain, and the several factors that produce high tides will displace a population, or reduce its size, to any great extent. (A.A.)

Keywords: salt marshes, mice populations, San Francisco Bay

V-C-11

Newman, J.R. 1970. Energy flow of a secondary consumer (Sorex sinuosus) in a salt marsh community. Ph.D. Thesis. University of California, Davis. 113 pp. (Diss. Abstr. 32:883-B)

The purpose of this thesis was to test the importance of the effects of certain abiotic and biotic factors on energy flow through higher consumers. In particular, the aim was to describe the energy flow through the salt marsh shrew, Sorex sinuosus.

The error of estimate attributable to certain abiotic and biotic factors ranged from one percent because of metabolic age differences of the population to 65 percent because of seasonal differences in the heat energy of respiration. The major biotic and abiotic factors affecting the energy flow through this secondary consumer are metabolic sexual differences, seasonal and daily metabolic rhythms, activity, digestive efficiency, ambient temperature changes, and prey availability.

Shrew densities varied with season and types of habitat. In optimum habitat areas, densities of 45 shrews per acre are found. The energy flow through the shrew population is estimated to be 105,615 kcal per acre per year. Because of low digestive efficiency, the energy intake is estimated to be from 132,000 to 210,000 kcal per acre per year. In terms of impact on the salt marsh community, the shrew population is the second largest energy consumer of the salt marsh small mammals. Potentially the energy consumption of shrews is greater than a number of primary consumers. Although shrews are not apparently limited by food supply, they could have a significant effect on the density and diversity of the invertebrate fauna. (A.A.)

Keywords: energy flow, salt marshes, secondary consumers, salt marsh shrew

V-C-12

Johnston, R.F., and R.L. Rudd. 1957. Breeding of the salt marsh shrew. *Journal of Mammalogy* 38:157-163.

Salt marsh shrews (*Sorex vagrans halicoetes*) are common inhabitants of the San Francisco Bay salt marshes in California. Their numbers in favorable marshes form perhaps 10 percent of the mammalian fauna present, the rest of which is chiefly composed of *Microtus californicus*, *Rattus norvegicus*, *Mus musculus*, and *Reithrodontomys raviventris*, all of which are more abundant than shrews. Field work was done from 1949 to 1955 in all of the San Francisco Bay marshes inhabited by salt marsh shrews. Shrews inhabit those parts of salt marshes that offer dense cover, an abundance of invertebrate animals as food, suitable nesting and resting sites, and fairly continuous ground moisture.

The shrew habitat is found on the medium high marsh about 6 to 8 feet above sea level; the habitat extends to lower marsh areas not regularly flooded by tidewater. Suitable areas within this expanse of marsh characteristically have an abundance of stranded driftwood and other detritus scattered in *Salicornia*, which ordinarily reaches one to two feet in height. Under these pieces of wood, moisture is retained fairly well into the autumnal dry period, and amphipods, isopods and other invertebrates are common in most seasons of the year. Nesting and resting cover for shrews is provided by the same driftwood and plant material. The latter includes the living *Salicornia*, but equally important is the dead material left by tidewater; most of this is *Spartina* duff. The higher marsh, 8 to 9 feet in elevation, is dry and has minimal cover and few or no shrews. The lower *Spartina* zone, subject to daily floods and lacking heavy cover, is devoid of shrews. (J.B.)

Keywords: salt marsh shrews, high salt marshes, detritus, Francisco Bay

V-C-13

Loveless, C.M. 1959. Everglades deer herd life history and management. Florida Game and Fresh Water Fish Commission Technical Report No. 6. 104 pp.

Studies were initiated in June 1955 to acquire a knowledge of the ecology of Everglades deer. The results of the studies serve as a basis for management and permit authoritative recommendations concerning establishment of water level regulations compatible with deer populations. Everglades deer (*Odocoileus virginianus seminolus* Golfman and Kellogg) occupy a range that encompasses approximately 2,000 square miles of seasonally flooded fresh water marsh located in southeastern peninsula Florida.

The report contains information on climate, vegetation, hydrology, fire, alligator holes, food supply and forage quality, harvest and hunting pressure, and other considerations and describes the relationship between these factors and the deer herd. (H.D.)

Keywords: deer herds, life history, Everglades, Florida

V-C-14

Self, C.A., R.H. Chabreck, and T. Joanen. 1974. Food preferences of deer in Louisiana coastal marshes. Proceedings of the twenty-eighth annual conference of the Southeastern Association of Game and Fish Commissioners, pp. 548-556.

Food preferences were determined for white-tailed deer (Odocoileus virginianus) in marshes and spoil areas along the Louisiana coast by using feeding trails with captive deer and browse surveys. Fifty species were offered to three deer during the feeding trials. The species selected in largest amounts were Leptochloa fascicularis, Scirpus olneyi, Iva annua, Echinochloa walteri, and Aeschynomene virginica. Preferred food plants during the browse surveys along marsh levees were Paspalum vaginatum, Mikania scandens, Bocopa monnieri, Panicum dichotomiflorum, and Leptochloa fascicularis. (A.A.)

Keywords: coastal marshes, deer, food habits, Louisiana

V-C-15

Harlow, R.F. 1959. An evaluation of white-tailed deer habitat in Florida. Florida Game and Fresh Water Fish Commission Technical Bulletin No. 5. 64 pp.

This study was undertaken to evaluate the vegetation types in Florida used as deer habitat. Its primary objectives were: (1) compare the different types of deer range in Florida, (2) list the major deer foods present in each vegetation type, (3) review the most common land use practices being carried out and attempt to evaluate them in terms of effects on the plant cover, (4) provide data which may be useful in developing techniques to improve deer habitat, and (5) determine the average densities of both deer and cattle in the various types of vegetation and evaluate the degree of competition between these two herbivores.

Habitat types examined included flatwoods, pine-oak uplands, swamps, hummocks, fresh water marshes, prairies, and sand pine-scrub oak ridges. Geographical distribution of major vegetation types, comparison of

vegetation types, food habits of deer, statewide deer population data, and recommendations for land use management are discussed. (H.D.)

Keywords: white-tailed deer, habitat, food preference, freshwater marshes, Florida

V-C-16

Harlow, R.F., and F.K. Jones, Jr. 1965. The white-tailed deer in Florida. Florida Game and Fresh Water Fish Commission Technical Bulletin No. 9. 240 pp.

This report attempts to review the many investigations conducted in Florida to date concerning white-tailed deer. The effect that these studies have had on the formulation of herd management policies is examined.

History, range characteristics, physical characteristics, deer herd dynamics, food habits, reproduction, diseases and parasites, management, exotic trees and shrubs, capture methods, census methods, radio telemetry, and economics are discussed. (H.D.)

Keywords: white-tailed deer, food habits, Florida

V-C-17

Payne, N.F. 1975. Range extension of the marsh rabbit in Virginia. Chesapeake Science 16:77-78.

A study of rabbits was conducted during the fall of 1962 and 1963 and the winter of 1963 on Hog Island State Waterfowl Refuge, located in the James River, Surry County, Virginia.

Extensive mud flats are exposed between the island and the mainland during low tide. The island contains 850 hectares, most of which was cultivated to accommodate migrating ducks and geese.

Marsh rabbits and cottontails were handled. Of 32 rabbits tagged and released, 15 (46.9 percent) were retrapped. The sex ratio of all marsh rabbits handled was essentially 1:1.

The average movement of marsh rabbits between captures, as determined from trap spacing, was substantially less than that of cottontails on Hog Island. Marsh rabbits have short legs and an awkward gait. Therefore, marsh rabbits might be reluctant to travel far. Perhaps for this reason, the number of days between captures was higher for marsh rabbits

than for cottontails. Marsh rabbits traveled less far and were exposed to fewer traps. (H.D.)

Keywords: marsh rabbits, Virginia

V-C-18

Pilson, M.E., and E. Goldstein. 1973. Marine mammals. Pages 7-1 though 7-48 in S.B. Saila, ed., Coastal and offshore environmental inventory: Cape Hatteras to Nantucket Shoals. Marine Publication Series No. 2, University of Rhode Island, Kingston.

Marine mammals are not notably abundant in the region from Cape Cod to Cape Hatteras. Some have never been common; others have been reduced or exterminated by man. Some 36 species--including seals, walrus, manatee, large and small whales, and porpoises--are identified as occurring regularly in this region at the present time, having occurred in earlier times, or as being sporadic or possible visitors. For each species, information and comment are presented on records of occurrence and abundance, breeding grounds if known, movements, feeding habits, and economic or esthetic importance. For most species, very little information is available for local populations, and their habits must be inferred from data gathered in other regions.

The local breeding populations of seals are very small, but are probably now stable or increasing. Most of the whale species that were formerly abundant in the region, but which were reduced by man, are now apparently increasing again. The only information available is that presented by occasional sightings and strandings of certain other species of whales and porpoises without previous commercial importance. (S.B. Saila, chapter synopsis)

Keywords: marine mammals, feeding habits, Cape Hatteras, Cape Cod

V-C-19

Wilson, K.A. 1959. The otter in North Carolina. Proceedings of the Thirteenth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 267-277.

The fall-winter foods of otters living along the coast consist largely of fish--principally carp, catfish, suckers, and sunfish. The otter's diet at other seasons of the year is largely composed of fish, blue crab, and crayfish. Other foods, all taken in small quantities, are shrimp, clam, water beetles, decapod, muskrat, rails, and waterfowl.

An examination of 53 female otters from northeastern counties over a 12-winter period (1947-48--1958-59) showed that breeding starts during January and continues into February and possibly into March.

North Carolina contains an estimated population of about 3,000 otters. Estimated populations on large untrapped refuges range from one otter for each 367 acres to one for each 1,100 acres. During the 1958-59 trapping season, 10 otters were trapped from about 5,000 acres of marsh in Currituck County. This is a yield of one otter for about every 500 acres of land.

Otters appear to travel more during the mating season than at any other time during the year, an estimated 10 to 12 miles. Families appear to live within an area of about nine square miles, from the birth of young in spring to the time of separation in fall or winter.

During twelve trapping seasons, 1947-48--1958-59, a total of 12,557 otters were harvested. A record yield of 1,514 animals was caught in the 1954-55 season. An epizootic that apparently struck following the destructive hurricanes in 1955 reduced yields to 687 otters in the winter of 1956-57.

The fur of North Carolina otters is ranked among the best in North America. The average price paid trappers in recent years varied from \$12 to \$22 per skin. Select black pelts sold in New York in 1957 brought up to \$48 each. (A.A. and G.S.)

Keywords: otter, food preferences, behavior patterns, North Carolina

D. Reptiles, Snails, and Insects

V-D-1

Chabreck, R.H. 1971. The foods and feeding habits of alligators from fresh and saline environments in Louisiana. Proceedings of the Twenty-Fifth Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 117-124.

Samples from fresh and saline waters in Louisiana showed little relation between foods eaten by young alligators and organisms available in these environments. Crustaceans were the principal foods in both freshwater and saline areas. Alligator stomachs from a freshwater area contained more than 6 times as much food as those from an adjacent saline area. The stomach capacity in the freshwater area was twice as great as in the saline area. The study suggests that young alligators that remain for extended periods in saline areas will have reduced growth rates as a result of reduced food intake. (A.A.)

Keywords: alligators, feeding habits, fresh and saline habitats, Louisiana

Joanen, T. 1969. Nesting ecology of alligators in Louisiana. Proceedings of the Twenty-Third Annual Conference of the Southeastern Association of Game and Fish Commissioners, pp. 141-151.

Rockefeller Refuge served as one of the last strongholds of the alligator in Louisiana, and with this in mind the project under report was begun to enable the Commission to re-establish this valuable species in a more efficient manner. The refuges comprise approximately 85,000 acres of coastal marshland, of which 25,000 acres are under the impoundment system of management. These marshes provide excellent nesting habitat for alligators, although certain marsh types are preferred over others. However, information was needed on the factors associated with reproduction, such as nesting success, nest predation, and habitat preferences, before definite plans could be formulated for the management of these reptiles.

During the summer of 1964, a study was initiated on the nesting ecology of alligators on Rockefeller Refuge. The objectives of the study were: (1) to determine activities of the female associated with nesting, especially during the incubation period, (2) to determine the nesting temperatures inside and outside the nest, (3) to determine the preferred nesting habitat, nest dimensions, number of eggs present in each nest, and reproductive success, and (4) to determine the kind and amount of nest losses on alligator eggs due to predation and other causes. During this study, nests were equipped with Stephens Model F Recorders, Taylor Temperature Recorders, and Short and Manson Hair Hygrographs. These instruments were used to record movement of the female over the nest, nesting temperatures inside the egg cavity, and relative humidity of the egg cavity. Data from the movement recorders indicate alligators pay little attention to their nest after the eggs are deposited. Each nest varied in the number of crossings, with one nest recording as few as 8 visits and one nest as many as 25 visits during the 65-day incubation period. The majority of the 66 visits tallied were recorded in the first, second, third, and ninth weeks of incubation.

Of the 315 nests followed during the course of the study, 79.7 percent were located in the natural marsh, 13.6 percent in the impounded marsh, and 6.7 percent on the levees.

It has been assumed that the alligator protects its nest from predators and intruders, but this was not demonstrated during the study. Several nests were destroyed by raccoons while the female was present at the nest site. At the 315 nests examined, only 29 females, or 9.2 percent, made any attempt to protect their nests when the site was visited by persons conducting this study. Weekly checks were made on each nest, and it was found that these 29 alligators were the only permanent residents at the nest site in the early weeks of incubation. As the incubation period progressed, only 24, or 7.6 percent, of the females were seen at the nest on the weekly visits.

The amount of predation by raccoons varied from one year to the next. However, predation followed much the same pattern for all nests, except a few that were destroyed in the early weeks of incubation. Predation was found to occur just after the eggs began to crack along the longitudinal axis, usually at the end of the seventh week of incubation.

Nesting occurred from the first week in June until the first week of July. However, the bulk of the nesting took place within a two-week period each year, and very few nests were located prior to or after this period. (G.S.)

Keywords: alligators, nesting ecology, coastal marshes, Louisiana

V-D-3

Kerwin, J.A. 1972. Distribution of the salt marsh snail (Melampus bidentatus Say) in relation to marsh plants in the Poropotank River area. Chesapeake Science 13:150-153.

The distribution and abundance of the salt marsh snail (Melampus bidentatus Say) was related to the distribution of marsh plants within a Virginia estuary. The animal was found in association with 10 species of marsh phanerogams, occurring with three plant species more than 50 percent of the time. These plants were Distichlis spicata, Spartina patens, and the short form of Spartina alterniflora.

Mean density per square meter was 0.23 within the brackish-water marsh and 7.24 in the saltwater marsh. The snail was not obtained by sampling in fresh- and slightly brackish-water marsh communities. (A.A.)

Keywords: salt marsh snail, marsh plants, estuaries, Virginia

V-D-4

Hausman, S.A. 1932. A contribution to the ecology of the salt marsh snail Melampus bidentatus Say. American Naturalist 66:541-545.

The salt marsh snail, Melampus bidentatus Say, is one of the smallest of the native Gasteropoda. It occurs all along the Atlantic coast and is the most common form of snail in salt marshes and tidal estuaries. Examination of the stomach contents of actively feeding individuals showed large quantities of fragments of epidermal cells of grasses, filamentous algae, and diatoms. Examination of excrement exhibited fragments of the same substances.

M. bidentatus is an important item in the diet of small fishes such as Fundulus, and is also preyed upon by various marsh and aquatic

birds such as song sparrows, marsh wrens, swamp sparrows, and red-winged blackbirds. (B.W.)

Keywords: salt marshes, snails, ecology, birds

V-D-5

Stiven, A.E., and J.T. Hunter. 1976. Growth and mortality of Littorina irrorata Say in three North Carolina marshes. Chesapeake Science 17:168-176.

This article examines the growth and mortality of the salt marsh gastropod (Littorina irrorata Say) over a one-year period. Three levels of population density were selected within three salt marshes in the Morehead City region of North Carolina.

Data were accumulated demonstrating high levels of net productivity of salt marsh vegetation, particularly in the southeastern regions of the United States. There is also strong evidence of the importance of decomposing salt marsh vegetation in the form of enriched detritus to estuarine production. Knowledge of the ecological roles of invertebrate salt marsh consumers indicates their significance as "macro-decomposers" in marsh food chains.

The authors conclude that mortality causes reflect probable different environmental conditions of each marsh rather than biological properties of the snails. Findings suggest that the support of various population densities is related to Spartina standing crop. However, the cause of this phenomenon is not clear. (H.D.)

Keywords: salt marsh, gastropods, productivity, North Carolina

V-D-6

Scheltema, R.S. 1964. Feeding habits and growth in the mud-snail Nassarius obsoletus. Chesapeake Science 5:161-166.

Nassarius obsoletus is primarily a deposit-feeder. The microflora to be found on the surface of sediment of intertidal flats serves as its major source of food. Living bivalves do not form part of the diet as previously reported. Dead organisms such as mollusks, crustacea, and fish are eaten when available but are not a principal item of food. Thallus algae are probably also utilized occasionally. Nassarius obsoletus may be regarded largely as a herbivorous species and deposit-feeder; however, it is also an omnivore and facultative scavenger.

Growth of Nassarius obsoletus occurs principally during the summer months. The winter is passed in a state of quiescence below mean low water. Zero- and one-year classes are readily distinguished, but after the third summer the various age groups can no longer be identified by the length-frequency method. The longevity of Nassarius obsoletus cannot be directly determined, but some individuals probably live to at least five years. A growth of 1.3 to 1.4 mm per month was estimated during the first two summers in a New England population found in Great Pond, Falmouth, Massachusetts. An increase in length of 3 to 5 times that at the time of metamorphosis occurs during the first summer's growth. (A.A.)

Keywords: mud-snails, feeding habits, intertidal flats, Massachusetts

V-D-7

Davis, L.V., and I.E. Gray. 1966. Zonal and seasonal distribution of insects in North Carolina salt marshes. Ecological Monographs 36:275-295.

The main purpose of this study was to describe the zonal and seasonal distribution of the principal species of insects from the herbaceous strata of the major types of salt marshes in Carteret County, North Carolina. The responses of these insects to flood conditions, and their trophic relationships, were also observed.

The salt marshes of the study area are classified as follows:

- (1) the Spartina alterniflora association, which occurs on substratum inundated at each high tide;
- (2) the Spartina-Salicornia-Limonium association, which occurs on substratum inundated at each high tide;
- (3) the Spartina-Salicornia-Limonium association, which occurs on slightly higher ground, and forms a narrow zone just above S. alterniflora;
- (4) the Juncus roemerianus association, which grows on flats inundated by spring tides, and occurs just above Spartina-Salicornia-Limonium;
- (5) the high marsh association, of which there are two principal facies, the first dominated by Distichlis spicata and occurring principally within or on the margin of Juncus marshes and at about the same elevation, and the second dominated by Spartina patens and usually occurring on sandy ground above the Spartina-Salicornia-Limonium zone, at a level seldom reached by high tides.

The insect assemblages of each type of marsh were sampled by sweeping the vegetation. The period of most intense sampling was June, July, and August, 1960, when sets of ten samples were obtained from twenty stations, of which six were established in S. alterniflora, one in Spartina-Salicornia-Limonium, four in Juncus, four in Distichlis, and five in S. patens. Samples were also taken monthly from one or more stands of each type of marsh from September 1, 1959, to June 1, 1960.

The ordinal composition of samples from stations included in the summer sampling program was determined. Homoptera predominated at fourteen

stations, of which five were in S. alterniflora, one in Spartina-Salicornia-Limonium, three in Juncus, three in Distichlis, and two in S. patens. Diptera were most abundant at the other six stations, and were second in abundance in samples from most stations at which Homoptera were predominant. Hemiptera, Orthoptera, Coleoptera, and Hymenoptera were also present at all stations, usually in much smaller numbers. Homoptera decrease, and other orders increase, in abundance as zone elevation increases.

The specific composition of the insect assemblages of each type of marsh was determined. The zonal distribution, frequencies, and densities of the principal insect species are illustrated in diagrams. Frequencies, densities, field observations, and special collections were used to construct an outline of the characteristic insect species of the summer aspect of each type of marsh.

Most of the characteristic insect species from all types of marshes are herbivores, and fall into these three categories: (1) those with chewing mouthparts, the most important of which are grasshoppers, feed on plant tissues; (2) those with piercing and sucking mouthparts, the homopterans and most hemipterans, feed on plant sap; (3) those with sponging mouthparts, mainly species of Diptera, feed on plant secretions. The principal carnivores in all types of marshes are spiders. The most abundant carnivorous insects are beetles, asilids, mosquitoes, and reduviids. Detritus-feeding ephydrid and dolichopodid flies are common in S. alterniflora, Spartina-Salicornia-Limonium and Distichlis. Dipterous larvae parasitize salt marsh plants, and the larvae of parasitic hymenopterans undoubtedly infect many species of salt marsh insects.

There is no evidence that members of any insect species encountered in this study ordinarily allow themselves to be inundated by rising water. Some kinds of salt marsh insects can swim, walk, or hop over the surface film, and others escape high water by flying. The seasonal distribution of the predominant types of insects, as indicated by their presence or absence in samples, is given. Several species of fulgorids and other homopterans, some dipterans, and a lygaeid, occur throughout the year in the adult stage. Orthopterans, beetles, most species of ants, parasitic hymenopterans, most cicadellids, and most kinds of hemipterans and dipterans are absent in winter. (Author's summary)

Keywords: insects, salt marshes, North Carolina

V-D-8

Cameron, G.N. 1972. Analysis of insect trophic diversity in two salt marsh communities. Ecology 53:58-73.

This study analyzes trophic relationships of the insect component of two intertidal salt marsh communities dominated by Salicornia pacifica and Spartina foliosa, respectively. Seasonality of that component

is determined and influence of physical microenvironmental factors on trophic diversity is assessed. Adult insect populations were monitored weekly, trophic diversity was computed, and relationships with primary production and litter accumulation were quantified.

Temporal diversity trends were similar in both communities although the amplitude was slightly greater in Salicornia. In both communities, herbivore diversity was highest during the spring months while saprovores diversity was highest during midwinter. Predator diversity responded to both herbivore and saprovores diversity, although it was more closely tied to herbivore fluctuations in Salicornia. Standing crop biomass was maximum during October and litter accumulation was highest during January.

Two classes of adult insects occurred: persistent species, representing a low percentage of the total species complement, were present as adults throughout the year in both marsh communities; seasonal species, on the other hand, were present as adults only during the growing season.

Seasonal succession in species of herbivores and saprovores reflected productional and transformational changes in plant matter; predators responded likewise, but more impressive was the numerical response to prey populations by particular predators. Correlations were high between each trophic group and its respective resource.

Physical microenvironmental factors, especially temperature and vapor pressure deficit, seemed to be important in cuing larval development, but did not exert a dramatic effect on adult diversity trends.

Several strategies of habitat utilization are considered. It is hypothesized that the persistent and seasonal species have evolved as specialists to avoid competitive interactions and maximize resource utilization. During annual expansion of resource states, the salt marsh insect component undergoes "species packing" wherein additional species enter the system temporarily to utilize the expanded resource base.

The study indicated that trophic diversity in both salt marsh communities has distinct seasonal patterns. Biological, rather than physical, factors play an important role in the distinction, although some physical factors are influential. The study further showed that there is a positive correlation between herbivore diversity and standing crop biomass, between saprovores diversity and litter accumulation, and between predator diversity and herbivore prey diversity. Predaceous insects in the salt marsh respond numerically to prey abundance, suggesting that they are host-specific. The host-specificity and lack of diversity of predaceous insects suggest the importance of other herbivore and saprovores predators.

Seasonal responses of consumers of several trophic classes to resource availability raise interesting questions concerning salt marsh community structure and in particular the relationship between seasonal richness and resource partitioning. The mosaic of vegetational parts increases in the spring when primary production begins. Subsequently, an increase in plant biomass and structural complexity occurs.

Several strategies are given concerning resource utilization by seasonal versus persistent species. One of these strategies is overlapping niches. In this situation, each species satisfies its own requirements while jointly using resources with other species. Overlapping niches lead to severe competitive interactions between species groups and, consequently, decreased diversity. Another strategy involves physiological adaptations to particular elements along the temperature-humidity gradient. Seasonal species could thus utilize resources in their zone of physiological tolerance more efficiently than, and without interference from, persistent species.

The strategy which the author believes to be operating assumes that seasonal and persistent species are both specialists, alleviating competition by resource subdivision. Specialization enables more species to coexist in an available habitat. (A.A. and H.D.)

Keywords: insects, trophic diversity, salt marshes

V-D-9

Barnes, R.D. 1953. The ecological distribution of spiders in non-forest maritime communities at Beaufort, North Carolina. Ecological Monographs 23:315-337.

Spiders as a group constitute one of the best indexes for the investigation of community structure, stratification, and succession of animals. The great degree of adaptive radiation which the order has undergone has resulted in their filling almost every ecological niche. Despite this and other advantages of study, few ecological studies had been made of spiders at the time of writing. Of the nine principal maritime plant communities in the region, the study was concerned with three in which the presence of salt water, directly or indirectly, was the determining factor as to their presence: Spartina alterniflora, Spartina-Distichlis-Salicornia, and Juncus roemerianus.

The variation in the saline water table was found to be the primary factor determining the formation of the major maritime plant communities and the zonal and successional series in which they occur. On the coast of North Carolina, the zonation and succession of vegetation consist of the following series of communities beginning in the intertidal zone and ending in the climax maritime forest: Spartina

alterniflora, Spartina patens, mixed herbaceous, Myrica-Ilex-Quercus shrubs, Persea-Ilex-Quercus shrubs and the maritime live oak forest. Also characteristic of the coastal area are the estuarine Juncus roemerianus and Spartina-Distichlis-Salicornia communities as well as the dune grass Uniola paniculata.

The structure of the spider populations was determined for each of these communities with the exception of the forest climax. The investigation was carried out at Beaufort, N. C., during 1951 and 1952. A total of 139 species of spiders belonging to 24 families were collected in the maritime communities. Each community was found to display a distinct population structure of spiders characterized both by the presence of certain species and by the relative density which each exhibits.

Sampling in ten different stands of Spartina alterniflora and in one stand over a two-year period indicates that the population structure of spiders living in this community exhibit a constancy not only in space but also in time. Thus, the abstract Spartina alterniflora community supports an abstract spider population that is essentially the same as that in any one concrete stand.

The three estuarine intertidal communities that occur in distinct zones support closely related spider populations, but the structure that each exhibits is sharply different. The dune community of Uniola is the most xeric of the maritime communities. This environment is reflected in the xeric species of spiders that the community supports, many of which are also characteristic species of the dry sand beach drift lines.

The zonation and succession of maritime vegetation produce a zonation and succession of spiders beginning in the intertidal communities and ending in the maritime forest. This succession, in general, is characterized by an increasing number of species and population density with proximity to the maritime climax. This may, in turn, be correlated with the increase in stratification of the intracommunity environment and the greater number of ecological niches afforded by the vegetation. (G.S.)

Keywords: spiders, marshes, community structure, North Carolina

V-D-10

Smalley, A.E. 1959. The role of two invertebrate populations, Littorina irrorata and Orchelimum fidicinium, in the energy flow of a salt marsh ecosystem. Ph.D. Thesis. University of Georgia. 135 pp. (Diss. Abstr. 20:2979-B).

Energy relationships of three components of a salt marsh on the Georgia coast were studied: (1) Spartina alterniflora, the only higher plant occurring on the marsh, (2) Littorina irrorata, a snail

and (3) Orchelimum fidicinum, a grasshopper. Net production of Spartina was determined by a periodic harvesting of the grass and calculation of the between-sample increase. Animal production was found by periodic harvesting and calculation of population biomass accumulation and biomass lost through mortality. Caloric equivalents of the three components were determined by combustion in a bomb calorimeter. Respiratory rates of the two animal species were determined over the size range of the animals and the temperature range which occurred in the marsh; total respiration of the population, as found by sampling in the marsh, was then found on an annual basis. The respiratory rates were converted to calories by Ivlev's oxycaloric coefficient, or a modification thereof. Ingestion in grasshoppers was determined by weighing feces under controlled conditions and then adding respiration and production. Ingestion for Littorina was found with the aid of a production/defecation ratio for Littorina obtained from the literature. From these data, production, assimilation and ingestion of the animals and net production of Spartina were compared on an annual basis.

Production and assimilation (which is equivalent to energy flow) follow a similar pattern in both snails and grasshoppers, but population density is a very poor indication of the actual biomass or energy flow of the populations. The snails were found to be present in two distinct population segments: a large-snail population of high mortality and constantly changing size due to variable recruitment and growth. The biomass of the large snails was so much greater than that of the small snails that, in spite of the greater respiratory rate per unit weight of the small snails, their net environmental significance was minor compared with the large snails.

The annual cycle of energy flow of the grasshoppers corresponded well with their only food source, Spartina, being high in the early summer and dwindling to zero by September. The energy flow of the snails was more constant, showing only a slight mid-summer peak caused by higher summer respiratory rates. The more constant rate of the snail's energy flow was in good agreement with the constant supply of detritus in the marsh and surrounding waters, from which the snails derive their food.

Utilization efficiency of Orchelimum (ingestion/net production of Spartina) was about 2 percent, indicating that the grasshoppers were in an environment which contained an abundant food supply. Assimilation/ingestion (based on populations over a year) was 36 percent for Orchelimum and 45 percent for Littorina; production/assimilation was 37 percent for Orchelimum and 14 percent for Littorina. It is suggested that the grasshoppers sacrifice efficiency of food concentration for a higher production rate, while Littorina, living in a food-poor environment, must expend a relatively large amount of effort in food-

getting, assimilate food efficiently, and consequently have a low production rate. (A.A.)

Keywords: invertebrates, energy flow, saltmarsh ecosystem, Spartina, productivity, Georgia

V-D-11

Odum, E.P., and A.E. Smalley. 1959. Comparison of population energy flow of a herbivorous and a deposit-feeding invertebrate in a salt marsh ecosystem. Proceedings of the National Academy of Science 45:617-622.

Frequently the autotrophic and heterotrophic components of an ecosystem are partially separated in space in that they are stratified one above the other (vegetation - soil on land; phytoplankton - sediments in water). The basic functions are also usually partially separated in time in that there may be a considerable delay in the heterotrophic utilization of a large portion of the net production of autotrophic organisms. Consequently, between the first and second trophic levels, the energy flow of the community is often divided into two broad streams resulting in two types of primary consumption: 1) direct and immediate utilization of living plant tissues by herbivores and plant parasites; and 2) delayed utilization of dead tissues and stored food by other consumers. This paper presents a comparison of the annual pattern of population energy flow of two invertebrate species, a grasshopper and a snail, which represent the two basic types of primary consumers described above. The grasshopper, Orchelimum fidicinum, is a strict herbivore, which feeds exclusively on Spartina alterniflora. The snail, Littorina irrorata, lives on the surface of the sediments and on the stems of marsh grass.

The annual cycles of numbers, biomass, and energy flow for both invertebrates are presented, as are measurements of net production of the low marsh Spartina and the authors' preliminary estimate of the rate of formation of Spartina detritus. The total annual energy flow of the grasshopper population was estimated to be 28 kcal/m²/yr, and the annual energy flow of the snail population was estimated to be about 290 kcal/m²/yr.

The authors point out that while different populations cannot be compared on the basis of numbers and biomass, valid comparisons can be made through the common denominator of energy flow. (B.W.)

Keywords: energy flow, invertebrates, annual cycles, biomass, salt marsh ecosystem

V-D-12

Smalley, A.E. 1960. Energy flow of a salt marsh grasshopper population. Ecology 41:672-677.

Analysis of communities by measuring the energy transformations of constituent populations is largely untried. Some energy flow measurements of entire ecosystems have been successfully undertaken, and a laboratory population has been the subject of study. This paper describes a study of the energy flow of a natural population of a grasshopper, Orchelimum fidicinum Rehn and Hebard, in salt marshes near Sapelo Island, Georgia.

Population density, growth rates, respiratory rates, caloric content, and rates of defecation were determined. Using these measurements, rates of ingestion, production, energy loss by respiration, and defecation were estimated for the population on an area basis. Over an annual cycle of about 100 days, production was 10.8 kcal/m²/yr; total energy flow was 29.4 kcal/m²/yr; and ingestion of Spartina alterniflora, the grasshopper's sole source of food, was 107 kcal/m²/yr.

Less than 1 percent of the Spartina was eaten by Orchelimum in the area studied. There are few primary consumers that eat the living, growing grass; there are a few species of Fulgoridae and some flies whose larvae may eat Spartina. Most of the Spartina production is passed on to decomposers in the marsh and surrounding water. (B.W.)

Keywords: grasshoppers, salt marshes, energy flow, Georgia

V-D-13

Lane, R.S. 1969. The insect fauna of a coastal salt marsh. M.S. Thesis. San Francisco State College. 78 pp.

The study was designed to survey the insect fauna of a salt marsh located near Dumbarton Point in Fremont, Alameda County, California. Comprehensive data were obtained by sweeping the dominant plant species--Spartina foliosa, Salicornia pacifica, and Distichlis spicata--on ten dates during the period July 4 to December 3, 1968. These plants were separated vertically and occurred in relatively homogeneous stands. Locally and typically, S. foliosa occupied the lower littoral, and D. spicata the upper littoral. Other collecting methods, such as aerial net, blacklight trap, corer, and collander, were employed to a limited degree to sample air, soil, and water.

It was found that 80 percent of all insects caught by sweeping were from S. foliosa. The most prevalent orders were Diptera and Homoptera, which ranked highest in abundance on each type of vegetation. Other orders that were present within each zone, but in considerably fewer numbers, were Coleoptera, Hemiptera, and Hymenoptera. Information

on the seasonal distribution of the insects is limited to summer and fall, the seasons during which the study was conducted. B.W.)

Keywords: insects, salt marshes, vascular plants, zonation, California

E. Fiddler Crabs, Marine Invertebrates, and Ecads

V-E-1

Teal, J.M. 1958. Distribution of fiddler crabs in Georgia salt marshes. Ecology 39:185-193.

Factors controlling the distribution of certain species of fiddler crabs, Uca minax, U. pugilator and U. pugnax, were studied in the Georgia salt marshes. The salt marsh is described and divided into two types: the Spartina marshes (tall Spartina edge marsh, medium Spartina levee marsh, short Spartina low marsh, short Spartina high marsh, and Salicornia-Distichlis marsh) and Juncus marsh. Sampling showed that the U. minax is found in certain parts of the short Spartina high marsh; U. pugilator is found on the tidal creek banks and in the Salicornia-Distichlis marsh; U. pugnax is found in all but the edge marsh, but is numerous only in the medium and short Spartina marshes.

Feeding experiments showed that the crabs could live on bacteria or fermented marsh grass mixed with mud or sand. This food is widely distributed in the marsh and is not, therefore, a factor in crab distribution. (L.H.)

Keywords: fiddler crabs, salt marshes, Georgia

V-E-2

Kerwin, J.A. 1971. Distribution of the fiddler crab (Uca minax) in relation to marsh plants within a Virginia estuary. Chesapeake Science 12:180-183.

The distribution and abundance of the red-jointed fiddler crab, Uca minax, was related to the distribution of marsh plants within a Virginia estuary. The crab was found in association with 15 species of marsh phanerogams, occurring with five plant species more than 20 percent of the time. These plants were Spartina alterniflora, Scirpus robustus, Distichlis spicata, Spartina patens, and Spartina cynosuroides.

Densities ranged from 0-76 burrows per square meter, mean densities being 7.88 within the brackish-water marsh and 14.35 within the salt-water marsh. The crab was not obtained by sampling the freshwater marsh. (A.A.)

Keywords: fiddler crab, marsh plants, estuaries, Virginia

V-E-3

Wolf, P.L., S.F. Shanholtzer, and R.J. Reimold. 1975. Population estimates for Uca pugnax (Smith, 1870) on the Duplin Estuary Marsh, Georgia, U.S.A. Crustaceana 29:79-91.

The study demonstrates that the technique of removal sampling can be modified for sampling populations other than small mammal populations for which it has been chiefly used. Sampling by removal was tested and applied to the Duplin Estuary Marsh to obtain an estimate of the population size and biomass of Uca pugnax. The mean population of the 1,975-ha. marsh was 205 crabs per square meter. Mean estimated wet weight of crabs per square meter was 41.6 ± 9.4 g. The mean estimated dry weight of crabs per square meter was 9.9 ± 2.3 g. An estimated caloric value of 22.2 kcal^{-2} was obtained. (B.W.)

Keywords: fiddler crab, estuaries, salt marshes, Georgia

V-E-4

Hedgpeth, J.W. 1950. Notes on the marine invertebrate fauna of salt flat areas in Aransas National Wildlife Refuge, Texas. Publications of the Institute of Marine Science, University of Texas 1:103-119.

This paper is a result of an ecological survey of the salt marsh areas of the lower part of the Aransas National Wildlife Refuge, Texas. The purpose of the study was to ascertain the food resources of this area for large wading birds, particularly the whooping crane (Grus americana).

Several species of large birds, including herons, ibises, roseate spoonbills, white pelicans and numerous smaller shore and wading birds frequent the area. Numerous tracks indicate a thriving population of raccoons and armadillos. Snakes and turtles also occur. The pre-dominant element of fish fauna of the ponds on these flats is composed of cyprinodontids of various species, with occasional influxes of mullet from the bay waters.

The invertebrate fauna is not rich in species although certain forms, especially the worms, grass shrimp and blue crab, are often abundant.

The nereid worms are evidently one of the staple items in the diet of many of the birds, including the whooping crane. Nereids and fiddler crabs are burrowers in the soft mud or sand of the salt flats.

Seventeen species of invertebrates, which might be termed marine or brackish water types, have been found in Aransas Refuge. These species include the pulmonate Melampus coffeus, which is found only among the salt marsh plants. It appears that the dominant invertebrate of the salt flats is blue crab, Callinectes sapidus. Crabs were observed at all stations, and their remains indicate their importance as a food item for both birds and racoons. Almost of equal importance in species mass is the shrimp Penaeus aztecus, but its occurrence is seasonal. Worms are apparently the base of the food pyramid on the salt flats, for there is little else on the bottom in the way of food for the crabs and shrimp, except each other.

The fauna of salt flat ponds is marine; above the three-foot contour line, this fauna abruptly ends except for the sporadic forays of individual blue crabs, and is replaced in the ponds and ditches of the higher ground by a fauna composed of crayfish, aquatic insects, freshwater entomostraca, ostracods, gammarids, and mollusks (H.D.)

Keywords: marine invertebrate fauna, salt marshes, birds, Texas

V-E-5

MacDonald, K.B. 1969. Quantitative studies of salt marsh mollusc faunas from the North American Pacific coast. Ecological Monographs 39:33-60.

The Spartina-Salicornia salt marshes of the North American Pacific Coast, and the tidal creeks that dissect them, contain distinctive molluscan faunas. These faunas exhibit a characteristic "structure," one or two species being widely distributed and very abundant while the remaining species are all represented by small numbers of patchily distributed individuals. When described in terms of the identity and number of species present and their respective relative abundances and size-frequency distributions, this "structure" remains fairly uniform between different sites within the same faunal province. The creek faunas usually contain more species and have a more variable species composition than do the marsh faunas.

The distribution of recurrent groups of species within the fauna supports the classification of Pacific Coast molluscan provinces proposed by Valentine (1966). There are some indications that both salt marsh and tidal creek environments in the Californian Province (27-34°N) contain a greater variety of species than do similar environments in the Oregonian Province (34-50°N).

Although the salt marsh molluscs occupy similar types of niches at each site (i.e., all epifaunal species feeding on algae and plant detritus),

the standing crop of the living animals increases considerably from north to south, possibly suggesting that the resources available within each niche increase at lower latitudes. Within the tidal creek environment, the number of types of niches occupied by the mollusc fauna does not appear to change with latitude, although the specific types do (infaunal and epifaunal species present, feeding types change with latitude).

The identity, relative abundance and size-frequency distributions of the more common species within the living fauna are adequately represented in their death assemblages. The assemblages differ significantly from the living fauna in both the total number of species and the absolute density. Thirty of the 62 species recorded from the death assemblages appear to represent introductions from other environments; all but two of these "accidental" species were represented by only a few (i.e., less than 10) individuals.

Although a wide variety of environmental parameters appear to affect the accumulation and distribution of dead material, many of the differences seen between the living and dead fauna can be explained by the local redistribution of empty shells by fresh water runoff and tidal activity.

Published evidence indicates that both salt marshes and the tidal creeks that dissect them represent distinct sedimentary environments. The results of this investigation therefore, in confirming that the community structure within these habitats is similar in the types of niches occupied, can help to explain the fact that comparable lithofacies of different ages often yield fossil assemblages containing closely related and ecologically similar species.

Of the models currently available in the ecological literature, only the logarithmic curve gives an adequate representation of the individuals-species relationships observed in the living fauna. The fit to observation is far poorer in the case of the death assemblages, but becomes adequate when all the species represented by single occurrences are eliminated.

The numbers of mollusc species found in the fauna of successively larger salt marshes or tidal creek systems are not significantly different. This suggests that increases in species diversity noted from successively larger regional samples may reflect the presence of a greater variety of habitats within the sample rather than a real enrichment of the fauna.

The results of this investigation suggest that quantitative studies of fossil assemblages probably can yield useful information on the evolution of the "structure" seen in present day communities of plants and animals. Since salt marshes and tidal creeks represent rather "specialized" habitats, it is essential that studies similar to that described here be conducted in other environments so that adequate

descriptions of modern living fauna and their relationship with contemporary death assemblages may be available for interpretation of the assemblages found in the fossil record. (Author's conclusions)

Keywords: salt marshes, mollusks, ecosystem, U.S. Pacific coast

V-E-6

Kuenzler, E.J. 1961. Structure and energy flow of a mussel population in a Georgia salt marsh. *Limnology and Oceanography* 6:191-204.

Modiolus demissus Dillwyn was studied near Sapelo Island, Georgia. The size distribution of the mussels was bimodal with maximum numbers in the dry weight (body) classes 0-24 mg and 400-599 mg. The total weight of mussels smaller than 200 mg was less than two percent of the total population weight. Random samples gave an estimated population density of $7.8/\text{m}^2$ for the entire inhabited marsh; the estimated organic biomass was $11.5 \text{ gm}/\text{m}^2$, one-third of which was body and two-thirds of which was shell conchiolin. The population was most dense near the heads of small creeks, averaging $32 \text{ mussels}/\text{m}^2$. The mussels, however, were not only more abundant in some types of marsh than in others, they were also clumped within areas of uniform marsh. Shell growth occurred throughout the year, especially in small and medium-sized individuals, but it was more rapid during the warm months.

The height-to-weight ratio changes with the seasons, the mussels being heaviest prior to spawning. Growth and mortality of mussels in flower pots in the marsh indicated a net annual population growth of $445 \text{ mg}/\text{m}^2$ (dry body weight) and a net annual mortality loss of $1200 \text{ mg}/\text{m}^2$. Allowance for bias would place the steady state growth-mortality rate necessary to just maintain the population somewhere between these two estimates. Population growth and gamete production accounted for an energy flux of about 13.9 and $2.8 \text{ kcal}/\text{m}^2/\text{yr}$, respectively. Respiration by the population accounted for approximately $39 \text{ kcal}/\text{m}^2/\text{yr}$, over two-thirds of which took place in air during ebb tide. Total assimilation amounted to $56 \text{ kcal}/\text{m}^2/\text{yr}$. (A.A.)

Keywords: mussels, energy flow, salt marsh, population structure, Georgia

V-E-7

Cuzon du Rest, R.P. 1963. Distribution of the zooplankton in the salt marshes of southeastern Louisiana. *Publications of the Institute of Marine Science, University of Texas* 9:132-155.

A plankton survey was made at fifteen stations in the saltwater marshes of southeastern Louisiana from July 1959 to March 1961. The

physical and chemical parameters (including temperature, oxygen, salinity, turbidity, and inorganic phosphate) were measured concurrently.

In the study area, where salinity ranged from 0.53 ppt to 25.43 ppt, one species of copepod, Acartia tonsa, dominated the zooplankton with 145,000 per five-minute haul and was abundant throughout the year.

There were few other populations. Numerically important copepod species were Eurytemora hirundoides, Pseudodiaptomus coronatus, Paracalanus crassirostris, and Oithona spp. Meroplanktonic elements such as nauplii and zoeae of Cirripedia also attained numerical importance.

Freshwater and marine fauna were localized and in minor numbers. A major zooplankton outburst occurred in April 1960. No comparable increase was recorded at any other time. Populations were more numerous in open water than in bayou samples. Smallest numbers were found in October. (A.A.)

Keywords: zooplankton, salt marshes, copepods, Southeastern Louisiana

V-E-8

Williams, R.B., M.B. Murdoch, and L.K. Thomas. 1968. Standing crop and importance of zooplankton in a system of shallow estuaries. Chesapeake Science 9:42-51.

The sequence, phytoplankton--zooplankton--carnivores, forms the classical food chain for the aquatic environment. Although the validity of this sequence for the open sea is unquestioned, studies on Long Island Sound and the English Channel indicated that even in these areas, 20 and 70 m deep, respectively, benthic animals are important consumers of phytoplankton. The significance of zooplankton as an intermediate step between phytoplankton production and carnivore production in shallower marine areas had been examined before. A year-long study of plankton in a system of shallow estuaries near Beaufort, North Carolina, provided an opportunity to make observations of phytoplankton production and the standing crop and taxonomic composition of zooplankton. These observations were used to estimate the importance of zooplankton in the energy flow of the area.

Previous work on the standing crop and taxonomic composition in estuarine zooplankton in the area consisted of detailed observations at a single location. Studies on other inshore areas along the eastern seaboard have yielded diverse estimates of zooplankton biomass. The range was from approximately 0.14 ml/m³ in a 1-m deep Cape Cod salt pond to 0.95 ml/m³ and 19 ml/m² in Long Island Sound.

Ten stations were sampled with a No. 10 net at 5-week intervals. Copepods predominated; meroplanktonic larvae were second in importance.

Standing crop ranged from 0.002 to 0.46 ml/m³ (displacement volume). Averages for the stations ranged from 0.089 to 0.149 ml/m³ and were not significantly different from one another. Averages for the surveys ranged from 0.033 ml/m³ in July-August to 0.285 in January. The standing crop was significantly greater in the winter than in the late summer. The annual average, 0.114 ml/m³, multiplied by the average depth of the estuaries, 1.18 m, yielded a standing crop of 0.13 ml/m².

A comparison of this data with other studies suggested that a small standing crop of zooplankton was typical of shallow embayments. For areas other than the open sea, standing crop was approximated by the equation:

$$\text{Zooplankton vol. (ml/m}^2\text{)} = 0.259 \times \text{avg length water column (m)}^{1.145}$$

Factors responsible for the scarcity of zooplankton in the Beaufort area were not identified, but temperature, food supply, and tidal flushing were eliminated as potential factors. Daily food consumption by zooplankton was estimated to be only 2 to 9 percent of the phytoplankton net photosynthesis. In shallow areas the importance of zooplankton as a part of the herbivore link in the food chain appeared inversely related to the average length of the water column. (A.A. and B.W.)

Keywords: zooplankton, estuarine systems, food chain, energy flow, biomass, North Carolina

V-E-9

Phleger, F.B. 1965. Patterns of marsh foraminifera, Galveston Bay, Texas. Limnology and Oceanography 10(Suppl.):R169-R184.

Populations of living foraminifera were studied from six areas of marine marsh in Galveston Bay. The general marsh foraminiferal assemblage is an Ammotium salsum-Miliammina frisca one, with common Ammonia beccarii, Arenoparrella mexicana, and Trochammina inflata, and also containing Ammonoastuta inepta, Elphidium spp., Tiphotrocha comprimata and Trochammina macrescens in somewhat smaller frequencies.

The following marsh environments have distinctive assemblages of foraminifera: (1) channel or bay bordering a marsh, (2) fringing Spartina zone, (3) Salicornia berm, (4) inner Spartina zone, (5) inner Salicornia zone, (6) lagoon barrier marsh, (7) "more saline" marsh, and (8) "less saline" marsh. Living populations are very small to very large, living-total population rates are large, and deposition rates are high.

Extreme range of environmental conditions limits the variety of marsh foraminifera. Knowledge of the environment is inadequate to explain distributions within the marsh. (A.A.)

Keywords: salt marshes, foraminifera, Galveston Bay

V-E-10

Nagle, J.S. 1968. Distribution of the epibiota of macroepibenthic plants. University of Texas Contributions in Marine Science 13:105-144.

The macrofauna, meiofauna, and epiflora of the southwest Cape Cod eelgrass and algal communities have been quantitatively studied in terms of vertical and peripheral distribution on individual plants, differences in areal distribution in one season, and seasonal changes in distribution patterns.

It was found that faunal abundance on individual plants varies with distance from the bottom and abundance of epiphytes. Some animals vary in peripheral as well as vertical abundance. In a locally varied habitat, amphipod populations show both dispersion and concentration. Areal distribution of the macrofauna varies with kinetic energy and salinity.

Seasonally, populations of mollusks epifaunal on eelgrass show a summer maximum coincident with breeding periods but also have high fall and winter maxima unrelated to breeding. Populations of eelgrass-dwelling amphipods not only exhibit the concentrated winter maxima of mollusks but also have several submaxima throughout the year. The amphipods breed throughout the year; the submaxima are related to the staggered breeding cycles of potentially competing species.

Summer populations tend to be stable and follow Gause's principle of competitive exclusion. Winter populations tend to be unstable, and competing species follow Gause's principle less closely. To persist, an epizoa species must be adapted to this physically unstable situation; it must be adapted to both its dispersed summer habitat and to the one winter habitat occupied by all epizoa. (A.A.)

Keywords: epibiota, macroepibenthic plants, macrofauna, mollusks, eelgrass, Cape Cod

V-E-11

Fox, R.S., and K.H. Bynum. 1975. The amphipod crustaceans of North Carolina estuarine waters. Chesapeake Science 16:223-237.

Seventy-four species of gammaridean (nine undescribed) and four species of caprellidean amphipods are reported from estuarine waters

of North Carolina. The range of Grandidierella bonnieroides is extended northward and that of Ampithoe valida, Argissa hamatipes and Corophium insidiosum is extended southward. Notes on habitats and zoogeography are included, as well as a key to identification. Most species occurring in North Carolina belong to an assemblage ranging from Cape Cod to northeastern Florida. Cape Hatteras does represent a significant faunistic boundary to estuarine amphipod species. (A.A.)

Keywords: crustaceans, estuaries, habitats, North Carolina

V-E-12

Brenner, D., I. Valiela, and C.D. VanRaalte. 1976. Grazing by Talorchestia longicornis on an algal mat in a New England salt marsh. Journal of Experimental Marine Biology and Ecology 22:161-169.

Grazing experiments using the carbon-14 dating method and an analysis of fecal pellets and gut contents established that the gammaridean amphipod, Talorchestia longicornis Say, ingests blue-green algae on algal mats in a Massachusetts salt marsh. This grazing had a measurable effect on the lower algal mat, where the density of T. longicornis was high. Exclusion of amphipods resulted in increases in chlorophyll a content, carbon incorporation, and nitrogen fixation. This effect was not seen on the upper mat where T. longicornis was less abundant. This assimilation efficiency of T. longicornis feeding on a diet consisting mainly of blue-green algae was surprisingly high (67 percent), considering that blue-green algae are usually considered as a poor quality food for herbivores. The population of T. longicornis seems to be annual, with growth of the overwintered juveniles in spring and early summer. (A.A.)

Keywords: salt marshes, fecal pellets, amphipods, algae, New England

V-E-13

Chock, J.S., and A.C. Mathieson. 1976. Ecological studies of the salt marsh ecad scorpioides (Hornemann) Hauck of Ascophyllum nodosum (L.) LeJolis. Journal of Experimental Marine Biology and Ecology 23:171-190.

The seasonal and spatial distribution of the free-living ecad scorpioides (Hornemann) Hauck of Ascophyllum nodosum (L.) LeJolis are described from the Great Bay Estuary System of New Hampshire-Maine, U.S.A. The growth and distribution of ecad scorpioides show a variety of phenological and distributional relationships between A. nodosum and the marsh grass Spartina alterniflora Loiseleur-Deslongchamps. A biomass maximum of ecad scorpioides was found in the fall during two consecutive years; it may be attributable to an influx of source material (i.e., A. nodosum) after storms, as well as normal seasonal growth of the ecad. Spartina

alterniflora provides initial stability for the progenitor fragments of ecad scorpioides and a protective canopy during the summer. Sexual reproduction of the ecad scorpioides was recorded only during one of the three years of study. The morphology and reproduction of ecad scorpioides is compared and contrasted with the attached A. nodosum, as well as with several detached ecads. A gradient of morphology is evident from typical A. nodosum to the extreme "marsh" ecad scorpioides. (A.A.)

Keywords: salt marshes, ecads, marsh grass, biomass, New Hampshire-Maine estuary system

V-E-14

Brinkhuis, B.H. 1976. The ecology of temperate salt-marsh fucoids; occurrence and distribution of Ascophyllum nodosum ecads. Marine Biology 34:325-338.

The distribution of several free-living Ascophyllum nodosum ecads, including scorpioides and mackaii, in a temperate salt marsh is described. Morphological characterization of these ecads by the presence or absence of air bladders and reproductive receptacles, and size and shape of fronds, indicated that several free-living forms occur throughout the marsh. Plants resembling the ecad mackaii were more closely associated with exposed areas along the low-tide regions, while scorpioides-type ecads prevailed on the Spartina alterniflora-dominated marsh banks and flats in the middle and upper intertidal regions of the marsh. Maximum biomass of ecads occurred during the spring months in the absence of S. alterniflora, whereas minimum ecad biomass was associated with maximum S. alterniflora densities in the late summer and fall months. Morphological differentiation of dwarf-type ecads was related to environmental components other than exposure to low and/or fluctuating salinities. (A.A.)

Keywords: salt marshes, fucoids, ecads, food habits

V-E-15

Brinkhuis, B.H., and R.F. Jones. 1976. The ecology of temperate salt-marsh fucoids; in situ growth of transplanted Ascophyllum nodosum ecads. Marine Biology 34:339-348.

Growth, in terms of length, weight, and number of branches and/or dichotomies, in transplanted specimens of Ascophyllum nodosum ecad scorpioides in a temperate salt marsh is described. The ecad scorpioides, when transplanted from its characteristic habitat on the mid-intertidal, Spartina alterniflora-dominated, marsh flats to a location near mean low-water, developed characteristics normally

associated with A. nodosum ecad mackaii. The growth of these plants was more rapid than those in the mid-intertidal region and was not affected by the shading of algal fronds by S. alterniflora. Unusually high temperatures and light intensities during the winter and spring months were major factors affecting growth in plants that were subjected to relatively long periods of tidal exposure. The presence of S. alterniflora during the summer months may act in a protective capacity for mid-intertidal ecad populations. (A.A.)

Keywords: salt marshes, fucoids, ecads, ecology

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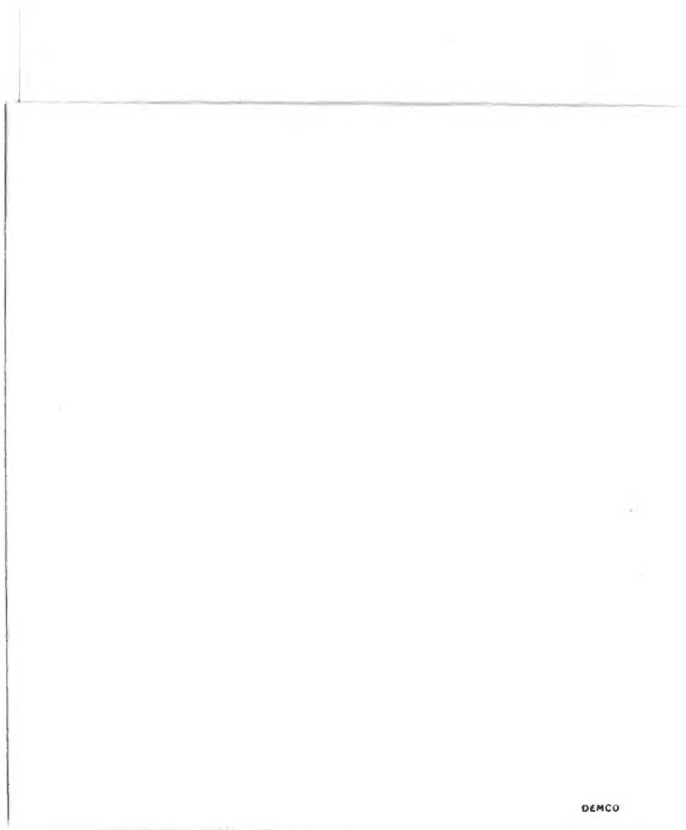
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